NUCLEONICS

The advent of nuclear electric power is heralded by this handwriting on a wall of the building housing the Experimental Breeder Reactor at the U. S. Atomic Energy Commission's reactor testing station at Arco, Idaho. For complete details, see page 72

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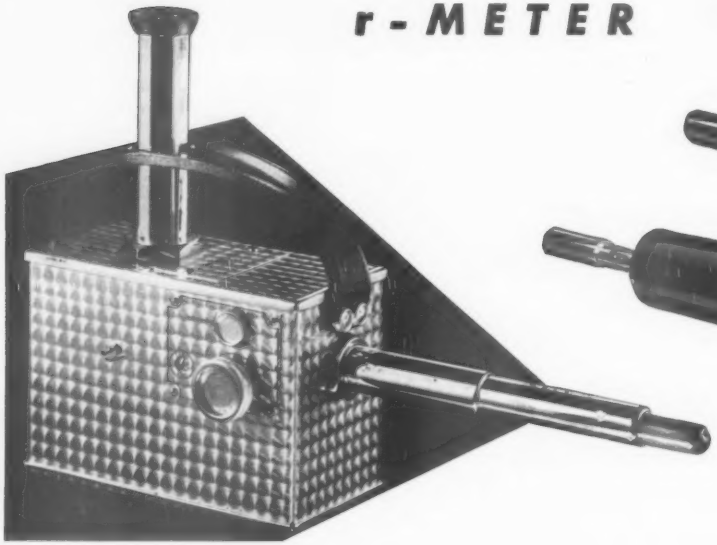

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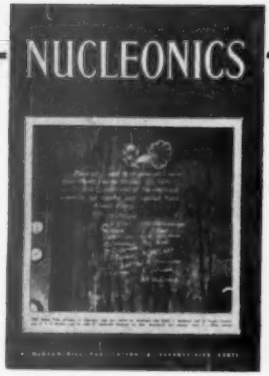

FEBRUARY • 1952
Vol. 10, No. 2

Wanted: Reactor Engineers... 10

Automatic Sample Separator for Radioactive Liquids... 14
A. E. BENNETT

Radiation Chemistry and Sterilization of Biological Materials by Ionizing Radiations... 19
JOHN P. O'MEARA

How to Load a Reactor... 24

CO_2 Ion-Chamber Techniques for Radiocarbon Measurement... 26
GORDON L. BROWNELL and HELEN S. LOCKHART

Analysis of Urine for Gross Radioactivity... 33
FREDERICK P. COWAN and JEROME WEISS

A Simple Low-Drift Electrometer... 36
F. M. GLASS

The Hazard Involved in the Use of Carbon-14... 40
HOWARD E. SKIPPER

Determination of Micromicrogram Quantities of Radium... 45
JOHN H. HARLEY and STEPHEN FOTI

"Air Equivalence" of Scintillation Materials... 48
WILLIAM B. ITTNER, III and MICHEL TER-POGOSSIAN

Molded Multi-Crystalline Stilbene for Scintillation Counting... 54
EARLE C. FARMER and IRVING A. BERSTEIN

Economics of Steam-Temperature Selection in Nuclear Power Plants... 57
ROGER D. ELLIOTT

Departments

EDITORIAL..... 9
CROSS SECTIONS..... 62
BOOKS..... 68
NUCLEONIC EVENTS..... 72
PRODUCTS AND MATERIALS..... 78
LETTERS..... 82

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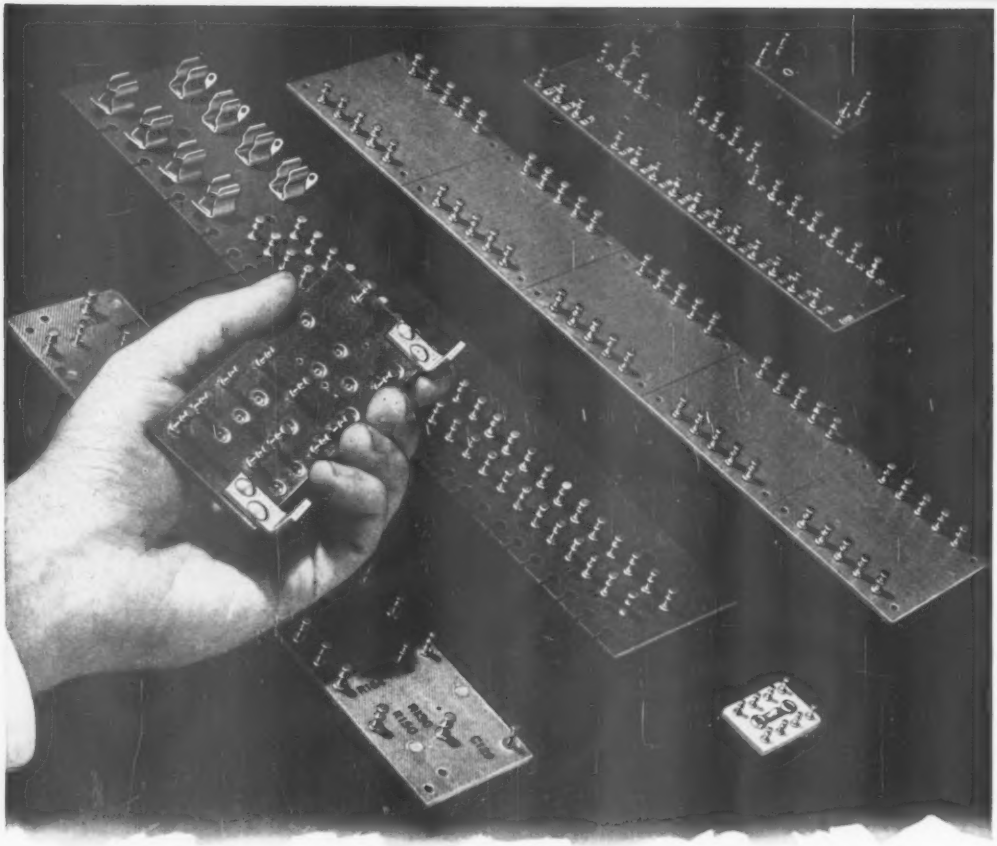

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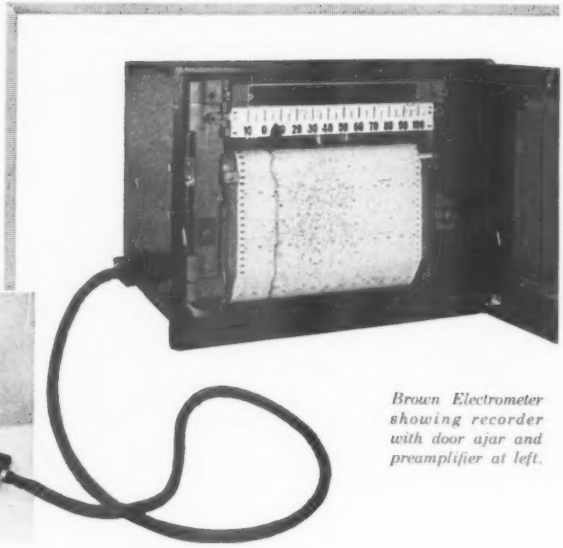
THE BROWN ELECTROMETER



Brown Electrometer showing recorder with door ajar and preamplifier at left.

for measuring and recording currents as low as 10^{-15} amperes

Electrical Characteristics

- Full Scale Current Ranges Available: 10^{-13} amperes with 10^{11} ohm resistor, and selector switch adjustment for full scale of 10^{-12} or 10^{-11} amperes. Using other resistors, full scale current ranges up to 10^{-7} amperes can be supplied with selector switch adjustment up to 10^{-8} amperes.
- Input Resistor: 10^{11} ohms for most sensitive current measurement. (Also supplied in values down to 10^{8} ohms.)
- System Accuracy: Approximately 1 per cent of scale.
- Zero Drift: Should not exceed 0.3 millivolt per day.
- System Noise: Approximately 5 microvolts.
- Instrument Speed of Response: Available for either 24, 12, or 4½ seconds full scale.
- Maximum Speed of Response Using 4½ Second Instrument Speed: 5 seconds for 90 per cent of change, with preamplifier located at source.
- Power Supply: 115 volts, 60 cycles. Also dry cell supplied in instrument.
- Power Requirements: 65 watts.

● *Important Reference Data*

ACCURATE measurement of extremely small currents is accomplished in this instrument through the use of a null balance servo system and a-c amplifiers that prevent drift and consequent instability. It is the only such system that incorporates a recorder as an integral part of the circuit. Designed to measure and record minute currents in ionization chambers, the Brown Electrometer may be used in any application where currents as low as a billionth of a microampere are encountered.

Features of the instrument include a special power supply to prevent false measurements from stray signals which might originate in an a-c power source . . . vibration frequency carefully selected to prevent phase shift . . . and automatic standardization of voltage across the slide-wire.

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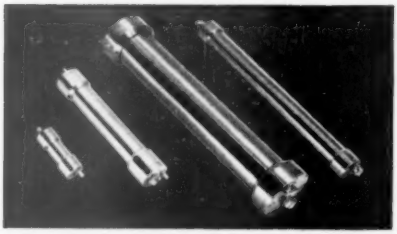

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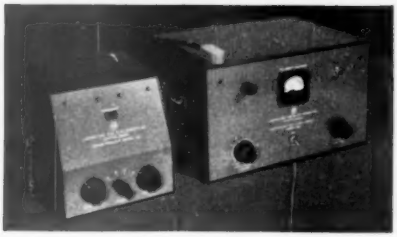

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Integrated recordings are made of the radiation that is present in the area during each fifteen-minute interval throughout a 30-day period.

The air-equivalent ionization chamber, pictured below, is the detector for the health monitor. It is available separately for use as a primary detector of beta, gamma, and x-radiation.

For more information on G-E radiation instruments, write for Bulletin GEA-5735, Section 605-12, General Electric Company, Schenectady, N. Y.

GENERAL ELECTRIC

605-12

THIRTY-DAY CHART makes permanent record of radiation in the monitored area.

COMPACT, HIGHLY-SENSITIVE ionization chamber with d-c amplifier is primary detector of radiation.

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NUCLEONICS

FEBRUARY, 1952

Power, Incidentally

Atomic energy continues to make history. Each new "first" scored in this field winds up in the front-page headlines. But, as always, these "firsts" are either things military or are byproducts of military work.

It is in this last category that the two historic events of the past several months fall—the British use of one of their reactors to heat a building and the U. S. hitching of some electrical equipment onto a reactor.

We do not mean to imply that byproduct developments are unimportant. Some of our most significant technological advances have stemmed from other work.

However, these two events are important primarily as symbols of what will come in the future, symbols of the practical and peaceful benefits which can be derived from atomic energy. They represent a target for the world to shoot at.

After the bombs were dropped on Hiroshima and Nagasaki, there was a wide public reaction of fear, awe and confusion about atomic energy. No one knew what to think the impact of this new force would be on the world of the future.

With vast areas of the world technologically underdeveloped and with gloomy forecasts about future availability of sources of energy, many dreamed about unlimited numbers of conveniently located nuclear power plants. More serious evaluations of the problems involved have long since shattered these dreams. Some evaluations are still quite optimistic; others are very pessimistic.

But the fact remains that we are not yet in a position to offer an answer to the question. We still do not have an operating nuclear power plant, one built for the purpose of producing power and with economic considerations in mind.

The Idaho reactor which was used to develop a token amount of electricity was designed primarily to test the theory of breeding fissionable fuel from nonfissionable uranium. Because this reactor operates with "fast" or high-energy neutrons, one of the principal technological problems associated with it has been the need to remove a large amount of heat from a very small reacting core. Liquid metals have been hailed as a heat-transfer medium which could do this. The experimental breeder reactor is now the first operating reactor to use a molten metal in this way.

The heat produced by the reactor was used to generate electricity. However, this power generation phase is incidental and is being carried out to secure experimental information on the handling of liquid metals at high temperatures under radioactive conditions and to get information on the extraction of heat from a reactor.

There is no doubt but that this experience will prove useful for future work on nuclear power plants. Similarly, information being accumulated in connection with the submarine reactors under construction will be valuable.

But this is basically all part of a concentrated short-range program. We are now at the point where, in the words of L. R. Hafstad, director of AEC's reactor development division, "we shall have to decide what the big reactors are going to be in the next chapter of the reactor program."

We must get started on a power program to parallel the military effort. Although we can't predict now what it will be, reactors are sure to play an important part in our future. According to Dr. Hafstad, "even if direct competition [with other sources of power] is not reached, it may be that there will be a reactor industry anyway just for its peculiar advantages." —*J.D.L.*

CLASS at the Oak Ridge School of Reactor Technology performing neutron-scattering experiments using neutron counters, linear amplifiers, and scalers. This is one of the rooms in ORSORT's new student laboratory building that houses an exponential reactor for student use

WANTED:
Reactor Engineers

A serious problem in carrying out present and projected expansions of this country's atomic-energy program is the shortage of competent reactor engineers. To help lick this problem, AEC set up the Oak Ridge School for Reactor Technology (ORSORT). Industry has already hired some of the school's graduates and is sending more of its engineers there. NUCLEONICS questioned the companies involved to find out why they sent men to the school, what they thought they were going to get out of it, and what jobs the men were put at when they returned. The answers to these questions are inspiring.

NEXT SEPTEMBER the Oak Ridge School of Reactor Technology (ORSORT) will start its third formal session of specialized training for selected engineers and scientists. These men, when they graduate a year later, will have the know-how needed to design and operate a nuclear reactor.

In 1950, to strengthen the nation's reactor program and the role of industry in it, the Atomic Energy Commission established ORSORT and invited industry to send experienced engineers to the school for training. AEC thereby provided a unique way for a company, which did not necessarily have previous access to classified information on reactors, to get a detailed view of the field of reactor technology —a view it could, for example, put to use in future industrial planning.

The first formal one-year course began in September, 1950, with 46 students. A brief pilot course, given earlier, had 18 trainees. At present, these 64 alumni are employed by 13 government agencies and 29 industries engaged in atomic-energy research or development. The 1951–52 session, which will not be completed until next September, has an enrollment of 67 students. Of this enrollment, 38 are student-employees of the Oak Ridge National Laboratory, which operates ORSORT for the AEC through Carbide and Carbon Chemicals Company.

Industry's Opinions

To get a clear picture of what ORSORT is doing, NUCLEONICS asked the companies that hired graduates, or sent employees to the school, what they thought of the training offered—and, more important, what plans they have for using these men in their industry. Their answers, given on the pages that follow, reflect the wide-spread interests of these companies in the development of industrial atomic energy, in general, and in reactors, in particular.

The challenge which the AEC offered industry when it invited reactor-program participation was accepted by two firms with the acknowledgment that the "industrial potential of nuclear energy will expand with time" and that "industrial scientific progress is a responsibility of industry." Another company expressed the feeling that their contribution would be "greater" if some of their "key engineers had a better understanding of nuclear technology."

Training student-employees at ORSORT was considered by almost all the companies as an "extremely worthwhile" investment. "Although our company is sacrificing manpower now," one instrument manufacturer said, "in the long run we feel we will be repaid many times over by cooperating with the AEC. For the nation's and our own good, we cannot afford to ignore what the AEC is doing for industry."

A public utility, while disclaiming the implication that atomic-energy reactors for electric power are "just around the corner," called ORSORT an "investment in long-range planning."

The development, design, and manufacture of special industrial processing equipment is looked upon by a food manufacturer as a "logical outgrowth" of the knowledge gained through ORSORT training. An oil company, in sending a man to the school, looks forward to the assistance this man can give the company in appraising the "feasibility of applying nuclear methods to new problems."

MARCH 1 DEADLINE

Prospective students for the 1952–53 session of the Oak Ridge School of Reactor Technology have only until March 1 to complete their application forms for admission. The forms, including acknowledgment of an Atomic Energy Commission security clearance, must be filed by that date for the session beginning on September 8, 1952. For forms and information, write Oak Ridge School of Reactor Technology, P. O. Box P, Oak Ridge, Tenn.

Facilities and Curriculum

Students are selected from two categories: Category A, recent graduates from universities; and Category B, representatives from (and sponsored by) industry and government agencies. All applicants must have a bachelor's degree or higher in chemistry, engineering, metallurgy, physics, or engineering-physics. Category A students are paid $285 per month for the training period; Category B students remain on their sponsor's payroll.

If a company has an active interest in reactor development or wants to get into the field, it can get an ORSORT-trained man in one of two ways—either hire a student graduate or cut loose one or more of its own employees for a year to take the course under company sponsorship.

The school was expanded in September, 1951, to accommodate more students, and existing facilities were remodeled. Since then, a new student laboratory building has been constructed. Equipped with the most modern radioactivity instruments and training aids, this building houses a counting room, three laboratory rooms completely fitted with services, a general research laboratory, and an exponential reactor, which is a noncritical pile designed for use in experimentation and demonstration work only.

In addition to getting a broad education in reactor technology, the students get an "excellent over-all picture of the going reactor program," according to one respondant to NUCLEONICS' survey.

Experience to date has shown that to get the most from the course the student must be a competent engineer with a "better-than-average" knowledge of math. Probably an engineering-physics background would best qualify a man. There is no doubt it is a "stiff course for the best-trained men with young minds, but the benefits are commensurate."

The work of the school is carried on in conformity with standards of graduate collegiate instruction, and students must be prepared to devote from 50 to 70 hours per week to the school program. Full AEC security clearance and U. S. citizenship are required.

The courses in the current curriculum are as follows:

- Reactor chemistry (36 hours)
- Nuclear physics (engineers, 72 hours; scientists, 36 hours)
- Reactor theory (180 hours)
- Experimental reactor physics (90 hours)
- Metallurgy and ceramics (72 hours)
- Engineering (scientists, 72 hours; engineers, 36 hours)
- Reactor engineering (72 hours)
- Reactor design problem or component development research (500 hours)

ORSORT's director is F. C. VonderLage. Its faculty is composed of experienced nuclear physicists and engineers who are also members of various ORNL divisions and devote a part of their time to research. Reginald J. Stephenson, on leave from Wooster College, is serving the 1951–52 session as chairman of the faculty.

For the results of NUCLEONICS' survey, turn page ➡

How is industry using ORSORT graduates?

NUCLEONICS' survey showed that industry has put some of the 46 engineers and scientists who completed the 1950–51 session to work at a variety of jobs. Here's what they are doing, according to statements from the companies:

Bendix Aviation Corp. Our graduate, a physicist, is engaged in reactor design studies. We feel that sending a man through the school is an extremely worthwhile investment. The curriculum is very good and is being improved further as experience is gained. We are confident that the students are given an excellent over-all picture of the going reactor program in addition to the training in reactor technology.

Carbide and Carbon Chemicals Co. Our three graduates are associated with the Oak Ridge National Laboratory, which Carbide operates for the AEC. One is engaged in criticality and control calculations as a part of the predesign study of a new reactor. He is working essentially independently with occasional guidance of a senior person. Another is one of two engineers carrying the responsibility on shift with assistance of technicians in making shakedown runs on components of a newly constructed reactor preparatory to putting it into operation. The third has joined ORSORT as an instructor and is, in addition, designing and preparing experiments for the student lab operated in conjunction with the school.

Consolidated Vultee Aircraft Corp. Our graduate is a nuclear engineer engaged on work connected with the development of an atomic-powered airplane.

E. I. duPont de Nemours & Co. Our graduates are members of the Reactor Technology Group of the company's Atomic Energy Division. These three men are currently assigned to Oak Ridge National Laboratory as part of a cooperative program which ORNL is carrying out for du Pont in connection with the Savannah River project.

Electric Boat Co. Each of our two graduates had formal education in marine engineering and naval architecture plus company experience in the design and construction of submarines. They are now actively engaged at the company's plant in Groton, Conn., in the application of nuclear power to the propulsion of submarines. Their work involves design and engineering of components and systems that will be applied in the extraction of useful energy from a nuclear power source and in the utilization of this energy for propelling a submarine.

Why is industry giving its men ORSORT training?

NUCLEONICS asked the companies who now have employees taking ORSORT training what these companies expect to get from sending their men to the school. Representative of the replies, which embrace a broad cross section of industry, were:

Allis-Chalmers Manufacturing Co. We expect to find the training our employee is getting at ORSORT useful in carrying out contract work for the AEC in connection with the utilization of fission products which requires the knowledge of reactor operation and its by-products. Another ORSORT-trained man whom we hired last year is already engaged on this project.

Boeing Airplane Company. We expect to evaluate the feasibility of airborne generation of nuclear power from an aircraft manufacturer's point of view. This approach to the problem is in keeping with the Boeing idea that industrial scientific progress is a responsibility of industry itself.

California Research & Development Co. The two employees we sent to ORSORT are being trained for work on a classified project being done by our company for the AEC.

Cities Service Research and Development Company, Inc. We feel that the industrial potential of nuclear energy will expand with time. In fact, we have already read of several buildings being lighted with electricity generated from nuclear energy. In time, this could become competitive with petroleum as a source of power; and it would be extremely valuable to have in our employ a man who is familiar with such competition. In addition, it is entirely feasible that future research work which we might carry out would include some phase of the application of nuclear energy. The training which our employee is receiving in this respect would be of considerable value to us.

Douglas Aircraft Company, Inc. We feel that nuclear energy has become a vital factor in modern existence, and every industrial organization concerned, or likely to be concerned, with this new force and its potentialities must keep abreast of progress in this important field. Therefore, it is our opinion that we shall be keeping abreast by having our employee take the course offered at ORSORT.

General Mills, Inc. Our company had three basic objectives in sending a man to ORSORT: (*1*) General Mills has been engaged in research and development work for the Atomic Energy Commission for several years. In connection with this program, we have felt that our contribution would be greater if some of our key engineers had a better understanding of nuclear technology. (*2*) We believe it is possible that during the next decade certain applications of nuclear technology may affect General Mills' business in the food industry. (*3*) If industrial applications grow out of the potential available in radioactive waste materials, the development, design, and manufacture of special industrial processing equipment would represent a logical outgrowth of General Mills' current activities for the AEC. Such an undertaking would require engineers with the training such as that given at ORSORT.

Hercules Powder Company. Atomic energy and its possible commercial importance have, of course, been of interest to Hercules for some time. Looking to the future when atomic energy may be of direct value to Hercules, the company requested that one of our men attend ORSORT.

Byron Jackson Company. Our company has developed many firsts in pumps for many industries. To do this, it has been necessary that we send engineers to many industrial plants to study their problems. In sending our man to ORSORT, we are merely following a long-established policy.

Metropolitan Edison Company. Sending our employee to ORSORT is an investment in long-range planning. It

General Electric Co. Our four graduates are engaged on the ANP (Aircraft Nuclear Propulsion) project, which will be centered at the company's plant at Lockland, Ohio. They are assisting with the development work on a nuclear-powered aircraft engine for the Air Force.

Monsanto Chemical Co. Both of our graduates occupy key roles as members of the staff of the Monsanto-Union Electric Company of Missouri project which is investigating the feasibility of a reactor to produce plutonium and power.

North American Aviation, Inc. Work of our two graduates is related to a technical and economical evaluation of reactors of various types. It is part of a broad study of converter, breeder, and power reactors from the standpoint of over-all efficiency, utilization of fissionable materials, capital and operating costs associated with procurement, fabrication and processing of fuel, and with operation of reactors and gaseous-diffusion plants. Constraints imposed by the national welfare and the limitations associated with raw materials will be considered in the study.

Phillips Petroleum Co. Employed in Idaho Falls, Idaho, at the Reactor Testing Station, our graduate is a reactor console engineer. He will control and operate the materials testing reactor, inspect controls, and operate various equipment and materials within this reactor.

Pratt & Whitney Aircraft. One graduate from the school is employed on the aircraft nuclear propulsion project which this company is carrying out for the Air Force.

Westinghouse Electric Corp. Our graduate is a member of the project department of our atomic power division. His specific duties involve both physics and engineering problems in connection with reactor problems.

Associated Universities, Inc. (Brookhaven National Laboratory). Our graduate is working in the BNL reactor division on reactor component design and testing.

U. S. Air Force. Two of the graduates are at Wright Field, one of them in the nuclear power branch there. Two other graduates are working on the aircraft reactor project at Oak Ridge.

USAF Air Materiel Command. Three of the graduates are at Wright Field, one in the power plant lab there and two in the air development center. Our fourth graduate is working on the aircraft reactor project at Oak Ridge.

Bureau of Aeronautics. One of the men is at the Naval Radiological Defense Laboratory in San Francisco, and one is with the Bureau of Aeronautics in Washington.

Bureau of Ships. The five graduates employed by BuShips are working on the nuclear ship propulsion project.

is not to be interpreted as an implication that we believe atomic-energy reactors for electric power are just around the corner. It is our thought that within the next decade or two their feasibility will probably be determined and our ability to make use of such new technological developments will be limited unless we have personnel trained for it.

Minneapolis-Honeywell Regulator Co. (Brown Instruments Division). The members of our organization who are taking courses at ORSORT and elsewhere are being prepared to join the company's growing nucleonic engineering laboratory manned by nuclear-research and instrument engineers. Although our company is sacrificing manpower now, in the long run we feel we will be repaid many times over by cooperating with the AEC. For the nation's and our own good, we cannot afford to ignore what the AEC is doing for industry.

National Lead Company. The interests of our company are constantly expanding and now range from titanium product production to the preparation of products for the Atomic Energy Commission. Such interests have made it imperative that we keep abreast of all the latest scientific achievements and especially those in the field of atomic and nuclear structure. ORSORT provided a way to do this.

Public Service Electric and Gas Company. Our employee is spending one year at ORSORT as an extension of his two-year Public Service Cadet Engineers Training Course which he had just completed. What Public Service will get from sending this man to the school depends upon development of the use of atomic energy to generate power.

Incidental benefits from our employee's attendance might be: (*1*) The application of liquid metals, now being used by the atomic-energy groups in connection with reactor cooling, to heat-transfer problems in the conventional power cycle, such as the reheating of steam in turbines. (*2*) The use of various special accessories, such as pumps, seals, and controls, being developed in connection with the atomic-energy program, in the more conventional power installations. (*3*) The use of isotopes for testing purposes, to measure flows, find leaks, corrosion etc.

Reynolds Metal Company. Our employee is attending ORSORT as part of our program exploring possibilities of aluminum in nucleonics.

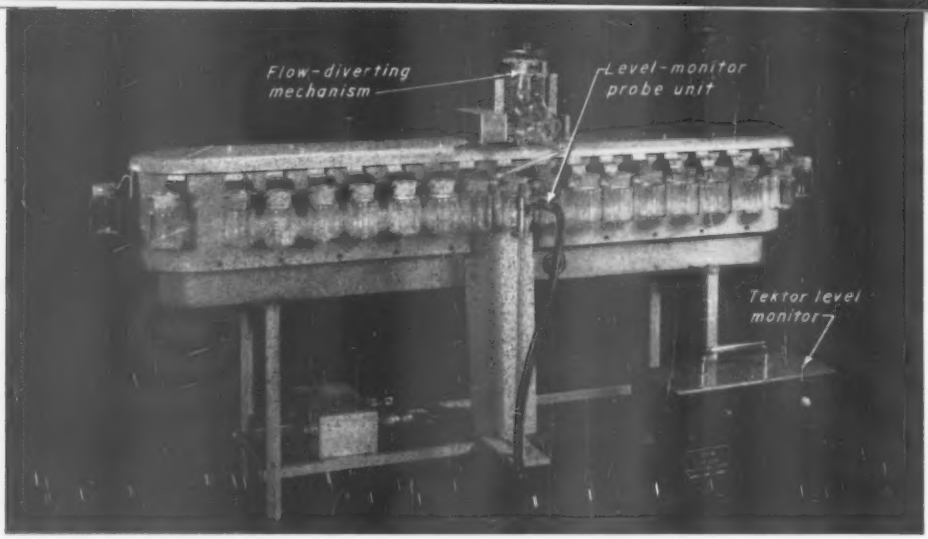
Sinclair Refining Company. There has been considerable discussion in recent years concerning the petroleum resources of our country. Although there is some conjecture as to the total reserves, it is apparent that they cannot last indefinitely. To meet this challenge our research organization has been considering the possible sources for the nation's future power requirements. Sending our employee to ORSORT represents another step in this investigation.

The industrial and research uses of radioactive fission products also have been the concern of this management.

In particular, we expect to use our man's knowledge in applying tracer techniques to help us evaluate the effects of some of the operating variables of commercial processes.

Present-day research has also demonstrated that radioactive substances can provide the triggering energy for chemical reactions. The petroleum industry in its production of petroleum chemicals, the polymerization of light hydrocarbons, and the alkylation process for the production of aviation gasoline may be able to utilize radiation-triggered chemical reactions.

Socony-Vacuum Oil Co., Inc. The points of value which Socony-Vacuum sees in sending our man to ORSORT are: (*1*) as a source of specialized information in connection with our own industrial radioactive research work; (*2*) in the appraisal of the feasibility of applying nuclear methods to new problems; and (*3*) in appraising the significance of industrial nuclear developments with respect to our own research work and business.



1 SAMPLE COLLECTING MECHANISM. Flow from ion exchange column passes through diverting mechanism to bottle for collection or to waste. If level monitor indicates full bottle or if activity passes a minimum, new bottle is moved into place

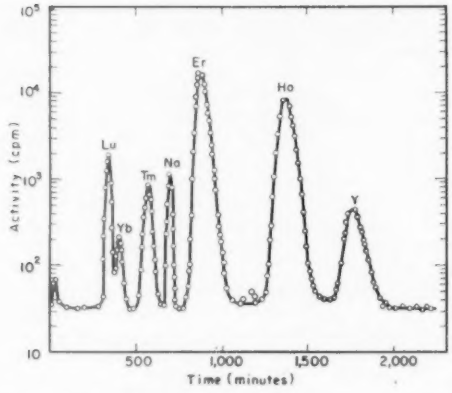
Automatic Sample Separator For Radioactive Liquids

An ion-exchange column can be used to separate fission products with each product producing a corresponding peak in observed activity. The device described here uses a three-in-one counting-rate circuit that detects these peaks with uniform accuracy over a wide range to control funneling each fission product into a separate container

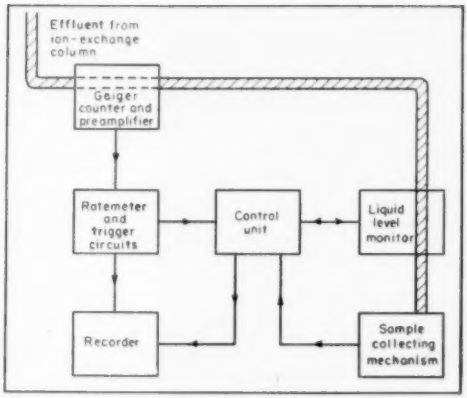
By A. E. BENNETT
Atomic Energy Research Establishment
Harwell, England

A LARGE PROPORTION of the fission products produced in a nuclear reactor can be separated by known processes such as precipitation, extraction, distillation, and electrolysis. But certain elements, notably the rare earths, cannot be dealt with by any of these processes.

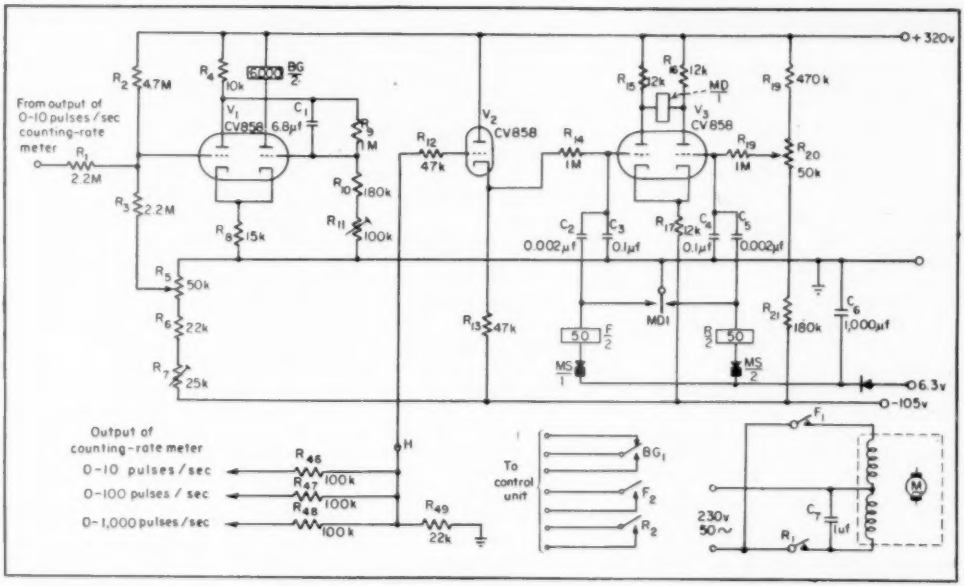
The ion-exchange process, however, can be used to separate the rare earths (*1*) and can be extended to deal with nearly all major fission products. For use with this process, completely automatic equipment has been designed that distributes the various separated elements into different containers and also gives a detailed record of the effluent activity. This equipment consists of the sample collecting mechanism shown in Fig. 1 and related electronic counting circuits and control units. A photograph of all the apparatus has been published by D. Taylor (*2*).



2 **TYPICAL RARE-EARTH SEPARATION.** Time required for separation and wide range of counting rates is evident



3 **BLOCK DIAGRAM** of collecting mechanism and auxiliary units shows relation of units



4 **TRIGGER CIRCUIT** makes it possible to combine outputs of three counting-rate meters to obtain uniform accuracy over wide range of control that is necessary in separating fission products

The fact that the apparatus is completely automatic is of great importance, for it thus is capable of freeing the laboratory staff from the routine of separations. A three-in-one counting-rate circuit is the key to completely automatic operation.

This apparatus is useful in detailed studies because the ion-exchange separation process is relatively slow. A solution of the mixed fission products is passed through a column of the ion-exchange material, generally an organic resin held in a glass tube. A process of selective exchange occurs, the various fission products being taken up by the resin. To free the absorbed elements, the column is washed out with the optimum eluting agent. The various fission products flow from the column in turn, depending on whether, in the presence of the eluting agent, they are loosely or tightly bonded to the exchange material. This separa-

5 DRIVE MECHANISM. Brackets for bottle-holding forks are attached to two sprocket chains. Pegs operate microswitches that stop drive

tion process is well illustrated by Fig. 2, which shows the relationship between counting rate and time for the beta-active eluate of a rare-earth separation.

Abilities of Unit

The effluent from the ion-exchange column flows through a length of thin capillary tubing that passes through the sensitive volume of a Geiger counter. As shown by the block diagram in Fig. 3, pulses from this Geiger counter pass via a preamplifier into a series of counting-rate meters that are coupled to an electronic trigger unit. This unit determines when the counting rate either passes through a minimum or falls below a previously determined value.

When the counting rate first exceeds a predetermined value, a signal is sent to a relay control unit. This actuates the sample-collecting mechanism to bring a bottle into position under the column. The effluent is then allowed to flow into this bottle until the control unit responds to one of the following conditions:

1. The counting-rate meters indicate that the activity has fallen below the preset level. In this case the flow from the column is diverted from the collecting bottle into a waste vessel. When the activity next rises above the preset level a new bottle is brought into position, and the effluent flows into this bottle.

2. The counting-rate meters indicate that the activity has passed through a minimum, i. e. a new element is flowing out (see Fig. 2). In this case a new bottle is brought under the column.

3. The liquid-level monitor indicates that a collecting bottle has been filled to a predetermined level. In this case an empty bottle is brought under the column.

In each case the control unit automatically recognizes the condition that has arisen and makes a permanent identification mark on one pen of a four-pen self-balancing recorder. The other three pens are used to record the outputs of the counting-rate meters continuously.

Geiger Counter

The Geiger counter used in this system is of the flow-through type described by Sharpe and Taylor (*3*). It is an ordinary tubular counter with the anode wire surrounded by a helix of thin glass tubing (wall thickness ~ 30 gm/cm^2) through which the liquid is passed.

The characteristics of the counter are: helix volume ~ 0.3 ml, operating voltage = 1,100 volts, plateau length = 200 volts, and plateau slope = 0.05% per volt. The all-glass construction used in this counter greatly simplifies cleaning and also allows the use of strong acids and similar reagents in the processing.

Ratemeter, Trigger Circuits

One of the problems that must be overcome in monitoring the effluent from an ion-exchange column is that the counting instrument must be able to record activities which range between a background level of a few counts per minute, and 10^4 or 10^5 counts per minute. This requirement can be met by using a linear counting-rate meter, but such instruments have an inherent disadvantage in that to maintain a uniform accuracy (expressed as a percentage of the actual counting rate) over a wide range of counting rates, it is necessary to switch from range to range. This is extremely inconvenient if the ratemeter is to be used in conjunction with automatic apparatus.

To overcome this difficulty, a logarithmic counting-rate meter (*4*) covering a range of from 1 to 10^5 pulses per second was initially used. However, it has been found necessary to seek an alternative, because the efficiency of this unit is limited when it is used to determine exactly where the effluent activity commences to rise above the background level (i.e., the point at which an element breaks away from the ion-exchange material).

The counting-rate meter now in use has been designed by Cooke-Yarborough and Pulsford (*5*). It incorporates three linear rate-meters in a single unit and does not require any form of mechanical range switching. In this model the pulses from the head amplifier are fed via three parallel limiter tubes into three separate linear rate-meters, whose ranges are 0–10, 0–100, and 0–1,000 pulses per second respectively. The outputs from these three channels are recorded simultaneously by three separate pens of the four-pen recorder, and the counting-rate is obtained from the most appropriate trace.

To obtain a voltage signal suitable for operating the subsequent trigger circuits, the outputs of the three channels are limited just above full scale and then are mixed in the resistance network R_{46}–R_{49} shown in Fig. 4. The limiting prevents damage to the meters in the lower ranges when the counting rate exceeds the maximum of those ranges.

It can be shown that the voltage measured at the top of R_{49} rises almost logarithmically over the counting range 0–1,000 pulses per second, thereby providing a uniform triggering accuracy over the total range of pulse rates. This accuracy could not be achieved if the trigger circuits were operated directly from the linear output of the 0–1,000-cpm counting-ratemeter channel.

To distinguish the minima in a series of activity peaks, this signal is applied to point H in the "trigger circuit," Fig. 3. Relay MD is a sensitive center-stable moving-coil relay which operates either relay F or R according to the polarity of the current flowing through it. These two relays, F when the activity increases or R when the activity decreases, govern the forward and reverse rotation of the servomotor M which drives the equalizing potentiometer R_{29}. This potentiometer moves

in a series of steps following the mixed meter outputs, the circuit constants being such that there are approximately 40 steps per decade. Each step is thus approximately 2% of the full scale, which means that the *MD* relay will not be operated by the majority of the fluctuations of the output caused by the randomness of the input pulses. To insure complete safety, the output is smoothed somewhat by the coupling time constant $R_{14}C_3$.

The relays *F* and *R* also send signals to the relay control unit, which insures that an operation of *F* following *R* (corresponding to a minimum) immediately causes a collecting bottle to be changed. The other trigger circuit, V_1, is actuated by the output of the 0–10 pulses per second range when it reaches any level predetermined by the variable resistor R_5.

Sample-Collecting Mechanism

This unit is shown is Figs. 1 and 5. In principle it comprises an endless chain which carries 36 stainless-steel forks, the collecting bottles being hung by their necks from these forks. The complete unit is 42 in. long, 12 in. wide, and its over-all height is 24 in. The spacing between hooks is 2⅛ in. This spacing is sufficient to allow standard bottles up to 4 oz in size to be hung on adjacent forks. If these bottles are not large enough, it is possible to operate the unit with either larger bottles in alternate positions, or to fit specially designed long bottles (up to a maximum length of 12 in. and a volume of 100–200 ml).

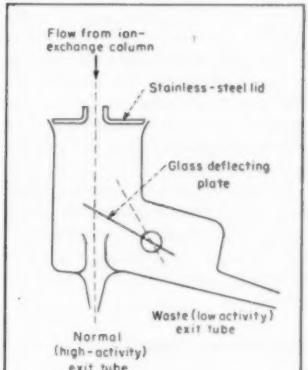
The endless chain is stretched between two sprocket wheels and has a number of L-shaped brackets rigidly attached. Each bracket carries an easily removed two-pronged stainless-steel fork. These have been made detachable so that different shapes may be fitted to carry various types of collecting bottles, and further, they are much easier to clean if they become accidentally contaminated.

To give rigidity to this assembly, a second endless chain is mounted on sprockets directly underneath the one just described, and fastened to it by a number of vertical straps. To insure that every bottle is brought into the same position under the column, each strap is fitted with a small peg which engages a microswitch as a bottle comes into position. One of the straps is fitted with an extra peg which engages another microswitch once per revolution of the chain. This is used to indicate that the assembly of bottles has reached a reference or "home position."

The mechanism is stopped merely by breaking the a-c supply to the unit, the motor speed and gear-box ratio having been chosen so that the positioning error due to any over-run in the motor is negligible compared with the width of a bottle neck. The time taken to bring the next bottle into position (assuming the mechanism is carrying its full complement of 36 bottles) is approximately ¼ minute.

Flow-diverting funnel. Mounted on the top of the mechanism is a two-way glass funnel (Figs. 1 and 6) that is used to direct the flow of the effluent from the ion-exchange column into either a collecting bottle or a waste vessel, according to whether the activity is above or below the preset value. Inside the body of the funnel there is a glass plate (approximately ¾-in. wide) in the form of a shallow tray mounted at an angle of 45 degrees on a glass rod that passes right through the funnel.

The rod and glass plate may be set into one of two positions by means of a small electromagnet and return spring. When the magnet is energized, the top edge of the deflecting plate is moved clear of the normal exit tube, and liquid dropping into the funnel falls straight through into a collecting bottle. When the magnet is not energized, the glass plate masks the normal exit tube and deflects the liquid flow into the side tube of the funnel, and thence to the waste vessel. It should be noted that there is no hold-up in the normal flow from the column and that any drops which splash off the deflecting plate collect in the bottom of the funnel and drain away into the waste vessel. The all-glass construction permits the use of corrosive reagents.



6 FLOW-DIVERTING FUNNEL. Glass deflecting plate covers normal exit tube; its position is controlled by electromagnet that is not shown

Liquid-Level Monitor

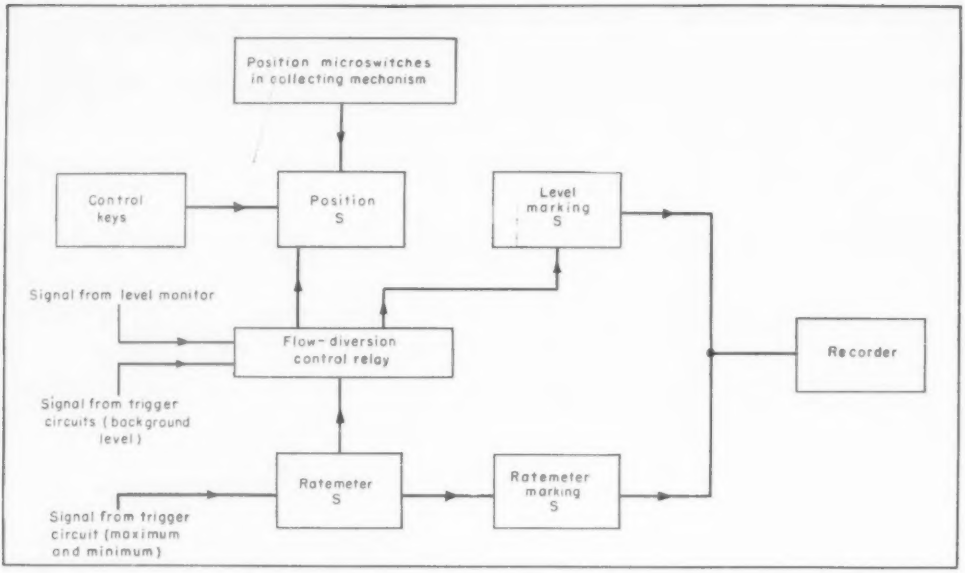
The purpose of this unit is to guard against a collecting bottle overflowing onto the surrounding equipment. This precaution is necessary because in many experimental runs the volume of liquid associated with a separated element is not known, and any spilt effluent would contaminate the equipment. Further, considerable damage might result from the chemical nature of the effluent.

The monitor used is a Tektor Proximity Switch* which is essentially a phase-balancing network that can detect very small changes in capacitance. In the present arrangement the probe electrode is a length of brass bar 3 × ¼ × ¼ in., mounted centrally on the end of a 6-ft probe cable, as shown in Fig. 1. The cable is held with the bar horizontal in a clamp that can be positioned in front of a collecting bottle. A grounded plate mounted behind a bottle increases the field intensity around the end of the probe and consequently the sensitivity of the instrument.

The Tektor operates on the change in capacitance that occurs as the liquid fills the bottle. A contact of the Tektor relay gives a signal to the control unit that a bottle change is required. As a full bottle moves away, the Tektor relay automatically releases, and the unit is immediately ready for re-operation on the next bottle. Any false operations of the relay arising from a bottle swinging on its hook as it moves into position are made ineffective by the main control circuit.

A further advantage of this level monitor, which is of particular importance when dealing with highly active solutions, is that only the probe electrode and cable need to be on the active

* Manufactured by Fielden Electronics Ltd., Manchester, England.



7 CONTROL UNIT. "S" denotes a relay scale-of-two in this block diagram. Four control keys are used to select desired mode of operation of the sample separator

side of a safety wall. This greatly facilitates maintenance of the unit.

Control Unit

The function of this unit, shown in Fig. 7, is to initiate and control the movement of the collecting mechanism on receipt of signals from the trigger circuits and the level-control unit. It comprises twelve relays, a small 50-volt d-c power supply, and four control keys. The latter are used to choose the facilities required in an experiment and also to test the correct functioning of the equipment. The following facilities have been provided:

1. It is possible to collect in each position of the mechanism, or alternatively only the bottles in either the odd or even positions may be used. This enables the mechanism to carry large bottles which may overlap two positions.

2. The mechanism can either make one complete change of bottles before it automatically shuts down, or it can run on indefinitely. This allows the effluent to be collected in more than the normal 36 bottles.

3. Provision is made to test the various units of the equipment both prior to, and during an experiment. In both cases the effluent is automatically deflected into the waste vessel.

4. This unit also controls the movement of the fourth pen of the recorder so that it is possible to deduce immediately from the record when a collecting bottle was changed, and whether this change was initiated by a minimum in the counting rate, by the activity falling below a predetermined level, or by a bottle becoming full. To correlate the record with the various bottles, the circuit is arranged so that at the beginning of a separation the collecting mechanism always moves round to the home position before the effluent is allowed to flow through the two-way funnel.

In the event of any misoperation of either the collecting mechanism or the control unit itself, the equipment is automatically switched off, and the effluent is diverted into the waste vessel.

Operational Experience

This equipment has been in operation for over eighteen months and has proved both efficient and reliable. Further, it has released the laboratory staff from extensive periods of routine counting, and has enabled a detailed study to be made of long separation processes which would otherwise have been impossible with a limited staff. A recent paper by Lister (*6*) outlines how it has been used in a detailed study of the cation exchange separation of zirconium and hafnium.

No opportunity has yet arisen for the equipment to be used in separating alpha-active liquids, but a suitable detector could be designed to replace the existing Geiger counter.

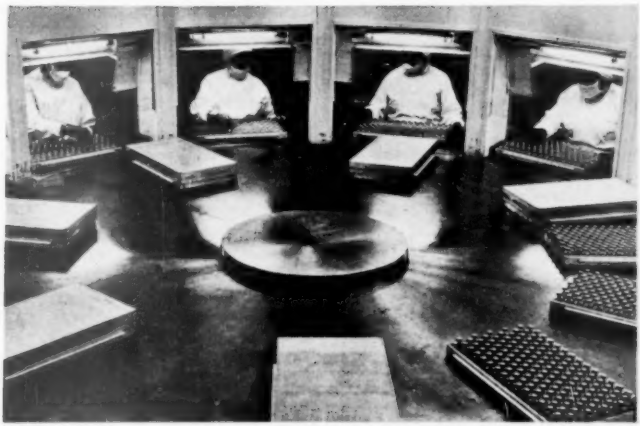
By the application of radioactive tracer techniques, it should be possible to extend the use of this or similar equipment to a much wider field of ion-exchange separations.

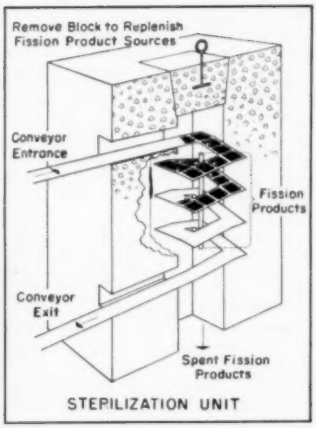
* * *

The author is indebted to his colleagues who contributed to the work reported here, and in particular to Mr. R. E. Whyard who carried out the final design of this equipment. This article is published by permission of the Director of the Atomic Energy Research Establishment.

BIBLIOGRAPHY

1. *J. Am. Chem. Soc.* **69**, 2769 (1947)
2. D. Taylor, NUCLEONICS 9, No. 6, 5 (1951)
3. J. Sharpe, D. Taylor, *J. Inst. Elec. Engrs. Pt. II* **98**, 222 (1951)
4. E. H. Cooke-Yarborough, E. W. Pulsford, *J. Inst. Elec. Engrs. Pt. II* **98**, 62 (1951)
5. A. E. Bennett, Report EL/R 688 (Atomic Energy Research Establishment, Harwell, England, 1951)
6. B. A. J. Lister, *J. Chem. Soc.* **691**, 3123 (1951)





TODAY (↑), part of the process of sterilizing penicillin involves such costly aseptic handling techniques and equipment as that seen at the left in use at Chas. Pfizer & Co., Inc., Brooklyn, N. Y. If some of the problems described in the article below can be licked, the fission-product sterilization unit shown at the right may be the process in use TOMORROW (↑)

Radiation Chemistry and Sterilization of Biological Materials by Ionizing Radiations

The problem of dealing with undesirable chemical effects produced in foodstuffs, pharmaceuticals, and biologicals sterilized by ionizing radiations is part of the greater problem of determining the usefulness of fission products for sterilization on a commercial scale. The nature of these effects and the conditions under which they occur are discussed

By JOHN P. O'MEARA

Southwest Research Institute
San Antonio, Texas

WORK on using ionizing radiations to sterilize biological materials has been carried on principally by the novel scientific partnership of food technologist and physicist. This review is offered with hopes of inducing the chemist to join the team, because the problems so far encountered have been primarily chemical. They are, furthermore, problems requiring the most refined techniques of chemistry for their solution.

This discussion will be limited to radiations that produce only ionization. Obviously, radiations that would also induce radioactivity in the material being sterilized could not be considered. We shall assume, then, that we are speaking of X-rays, gamma rays, or cathode rays of about 1 to 5 Mev.

Bactericidal Effects

The concept of utilizing the bactericidal action of ionizing radiations is not new; in fact, in 1896, the year after Roentgen discovered X-rays, a German paper (*1*) appeared entitled "*On the Question of the Effect of Roentgen Rays on Bacteria and the Possibility of Their Eventual Application.*"

Since 1920, many papers have been published concerning the effects of ionizing radiations of all types on microorganisms. One result of this work was the commercial application of ultraviolet lamps for surface sterilization. Application of more penetrating radiations, such as cathode, gamma, and X-rays, has awaited availability of sources capable of delivering the large doses required for sterilization.

An intensive investigation of the feasibility of utilizing high-voltage X-rays and cathode rays for the com-

TABLE 1—Typical X-Ray Doses

Weekly maximum permissible dose to whole body	0.3 r
Weekly maximum permissible dose to hands only	1.5 r
Chest X-ray dose (photofluoroscopic)	1.0 r
Probable lethal dose (whole-body radiation, single dose)	400 r
Total therapeutic dose to small, isolated tumor (administered in 10 to 20 treatments)	4,000 r
Complete destruction of radiosensitive microorganism (*Pseudomonas fluorescens*)*	>25,000 r, <100,000 r
Sterilization of raw milk*	>500,000 r, <1,000,000 r
Complete destruction of radioresistant microorganism (spore former isolated from catgut suture)*	>1,500,000 r, <2,000,000 r

* Data taken from Dunn (*9*)

mercial sterilization of foodstuffs, pharmaceuticals, and other biological substances was initiated at Massachusetts Institute of Technology in 1942 (*2*). Electronized Chemicals Corporation in Brooklyn has been active in this field for about the same period (*3*). The Atomic Energy Commission is now sponsoring studies (*4, 5*) at MIT, Columbia University, University of Michigan, and Stanford University to investigate the possible use of fission products for sterilization.

It is unfortunate that many of the reports eventually reaching the press (*6, 7*), and even some in the scientific literature, are somewhat misleading. Much public misunderstanding has resulted from the implication (which may not have been intended by the original investigators) that radiation-sterilization should be superior to heat-sterilization because of the low temperature-equivalence of the ionizing energy required for a killing dose. This arises from the well-publicized fact (*8, 9*) that the most resistant microorganisms are destroyed by a radiation dose that raises the over-all temperature of the medium on the order of 2° C.

It is true that conventional forms of heat-sterilization produce undesirable changes in many substances, such as the production of off-flavors, discoloration, coagulation and denaturation of proteins, and destruction of biologically active compounds. The need for a method of "cold" sterilization, or at least one that does not have the disadvantages of "hot" sterilization, is obvious. It will be pointed out later that radiation-sterilization (i.e., cold sterilization) may, under some circumstances, produce chemical changes that are more objectionable than those resulting from heat-sterilization.

It is not intended to pass judgment on radiation-sterilization as a substitute for heat-sterilization, for this would require an evaluation of the technique not only from the standpoint of the chemical reactions produced but also from the standpoint of cost, efficiency of energy utilization, volume of material that can be handled, necessary pre- or post-treatment of samples, and so forth. It is certainly too early to predict what the ultimate value of atomic energy for sterilization will be. Indeed, there is convincing evidence that radiation-sterilization may be useful for certain types of biological materials inadequately sterilized by conventional methods.

Radiation Doses Required

Table 1 shows the radiation doses involved in sterilization studies in comparison with the more familiar doses used in radioactive-tracer work and cancer therapy.

For sterilization work, which refers to a 100% kill, one deals with very much higher radiation doses than are met in usual X-ray practice. In most biological materials, it requires around 10 times more radiation for a 100% kill than is necessary for a 99% kill. This is due to the fact that the natural microbial flora contains both sensitive and resistant microorganisms. Spores are, of course, more resistant than vegetative cells.

Another fact that should be emphasized is that the 10-fold increase in radiation dose required to destroy the last 1% of viable microorganisms may be accompanied by a 5 to 10-fold increase in undesirable chemical effects.

TABLE 2—Reactions Resulting from Irradiation of Aqueous Solutions

PRIMARY REACTIONS

$H_2O \longrightarrow H_2O^+ + e^-$

$H_2O^+ \longrightarrow H^+ + OH$

$H_2O + e^- \longrightarrow H + OH^-$

SECONDARY REACTIONS

$OH + OH \longrightarrow H_2O_2$

$H + H \longrightarrow H_2$

$OH + OH \longrightarrow H_2O + O$

$2\,O \longrightarrow O_2$

$H_2 + OH \longrightarrow H_2O + H$

$H_2O_2 + H \longrightarrow H_2O + OH,\ H_2 + HO_2$

$H + O_2 \longrightarrow HO_2$

$H_2O_2 + OH \longrightarrow H_2O + HO_2$

$HO_2 + HO_2 \longrightarrow H_2O_2 + O_2$

$HO_2 + H \longrightarrow H_2O_2$

$HO_2 + OH \longrightarrow H_2O + O_2$

$H_2O_2 + HO_2 \rightarrow H_2O + O_2 + OH$

$H + OH \longrightarrow H_2O$

Chemical Effects

Very early, chemists amassed evidence to indicate that, despite the negligible over-all temperature-equivalence of the energy involved, ionizing radiations do produce widespread chemical changes in materials of biological interest. In fact, the changes are so widespread that one can say that, under suitable conditions, almost any substance that can be oxidized will be oxidized and almost any substance that can be reduced will be reduced.

At first, these oxidations and reductions were thought to occur through the action of hydrogen peroxide formed on irradiation of water, but it soon became apparent that much more vigorous oxidizing and reducing agents must be involved. This led to the "activated water" hypothesis attributed to Risse (*10*) and developed in detail by Weiss (*11*) and others. Much of the present knowledge in the field of radiation chemistry is interpreted in terms of the indirect action of ionizing radiation through the medium of an "activated solvent," which in turn causes the oxidations and reductions.

The possible mechanisms by which radiation-induced chemical changes are produced have been reviewed by Burton *et al.* (*12–16*), and will give the interested reader a coverage of the literature on radiation chemistry.

Table 2 lists the reactions by which free radicals are thought to be formed in the irradiation of aqueous solutions. They are the result of various recombination reactions involving the primary products, which appear to be H and OH radicals. Many of the radicals

Total Energy vs. Distribution of Energy in Sample

A number of reports on cold sterilization have compared the *total* amounts of energy involved in sterilization by heat and by radiation, but there seems to have been no attempt in those papers to point out the possible significance of the *distribution* of the energies absorbed by the sample. The following approximate calculations illustrate important differences in the manner in which thermal and ionizing energy are absorbed by the sample molecules—differences that influence the chemical changes occurring during sterilization.

Consider 1 gram of an aqueous solution to be sterilized by radiation or by heat. Heat-sterilization might involve raising the temperature of the sample from 25° C to 125° C, under pressure, so that heat of vaporization is not included. Radiation-sterilization might involve the application of 1,000,000 roentgens of ionizing radiation. The *total amounts* of energy supplied, expressed in units of electron volts, are:

By heat:

$$E = 100 \text{ gm-cal} \times \frac{1}{2.39 \times 10^{-8} \text{ gm-cal/erg}} \times \frac{1}{1.6 \times 10^{-12} \text{ erg/ev}} = 2.6 \times 10^{21} \text{ ev}$$

By radiation:

$$E = 1 \times 10^{6} \text{ gm-r} \times 5.2 \times 10^{13} \text{ ev/gm-r} = 5.2 \times 10^{19} \text{ ev}$$

Radiation, therefore, accomplishes the same sterilizing effect with about one fiftieth the total energy required by heat alone.

The distribution of the heat energy is essentially uniform throughout the sample. The energy absorbed per molecule of water is:

$$\frac{2.6 \times 10^{21} \text{ ev/gm}}{3.34 \times 10^{22} \text{ mol/gm}} = 7.8 \times 10^{-2} \text{ ev/molecule}$$

The distribution of ionizing radiation is non-uniform, the energy being given up in discrete amounts by the process of ionization and excitation.

The ionization of water, which leads to the formation of strongly oxidizing and reducing radicals, approaches yields of the order of 1 molecule ionized for each 30 ev absorbed by the solute. This does not mean that *all* of the energy goes into ionization, for only about 12 ev is required to eject an electron from the water molecule. The remainder of the energy goes into kinetic energy of the ion pairs formed, and in excitation. Neglecting the contribution of excitation reactions, it is apparent that 1×10^{6} gm-r ionizes

$$\frac{5.2 \times 10^{19} \text{ ev}}{30 \text{ ev}} = 1.4 \times 10^{18} \text{ molecules},$$

most of them water. The resulting H and OH radicals are strongly oxidizing and reducing, and even though most of them will undergo self-neutralizing reactions, the 1% or so that do react with the solute are by no means insignificant.

The role of excitation in causing chemical changes is not well understood, but it is known that the amount of energy transferred per molecule is several orders of magnitude larger than that involved in thermal sterilization.

Discussion: Even though about 50 times more energy is required for sterilization by heat than by ionizing radiations, the thermal energy is distributed so uniformly that the small amount of energy absorbed *per molecule* is not sufficient in itself to rupture chemical bonds. The main effect of heat is probably catalytic.

Radiation-sterilization, on the other hand, ignores the greater portion of the molecules in the sample. However, the few that do absorb energy are raised to energy levels far in excess of those required to break the chemical bonds of the solvent, and the resulting end-products are strongly oxidizing and reducing. The number of such radicals produced is not negligible, since the concentration of many biologically active compounds in foods is the same order of magnitude. The reaction of these "activated solvent" molecules with various solute molecules leads to end-products that are often more undesirable than those encountered in heat-sterilization.

The methods applied to reduce undesirable chemical reactions during radiation-sterilization have consisted of (*a*) altering the constitution of the sample so as to favor removal of the active radicals by non-noxious reactions, or (*b*) altering the physical state of the sample so as to restrict the movement of the active radicals, thereby favoring self-neutralizing reactions.

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are strong oxidizing and reducing agents, and the net effect to be expected in the irradiation of a solution will depend on the relative quantities of the various radicals present, their lifetime, and their mobility in the solution. These, in turn, are affected by the energy of the incident radiation, the radiation density along the ionization track, the presence or absence of dissolved oxygen, the viscosity of the solution, and the presence in the solution of oxidizable or reducible compounds which may "compete" with one another for the free radicals.

With this brief review of the agents that produce the chemical changes, let us look at some of the reactions that actually occur in practice.

Inactivation of Enzymes

The radiosensitivity of enzymes is of interest because of its possible relationship to the biological effects of radiations on living cells. It is also of practical interest in sterilization because it is usually necessary to prevent enzymatic spoilage as well as microbial spoilage. In heat-sterilization, the thermal inactivation of enzymes usually coincides with the thermal destruction of microorganisms.

This is not necessarily true of radiation-inactivation, and it illustrates graphically the marked difference in the nature of the two sterilizing agents. One hears the statement that enzymes are extremely radiosensitive and then, again, that they are extremely radioresistant. Both statements are equally true, providing the experimental conditions are specified.

Barron (*17*) has been able to demonstrate nearly complete inactivation of several enzymes in very dilute solu-

TABLE 3—Effect of 3-Mev Cathode Rays on Phosphatase and Peroxidase in Unfrozen and Frozen Raw Milk (*24*)

Dose (rep)	Phosphatase activity		Dose (rep)	Peroxidase activity	
	Unfrozen	Frozen		Unfrozen	Frozen
0	+	+	0	+	+
500,000	+	+	300,000	+	+
1,000,000	+	+	500,000	+	+
5,000,000	+	+	1,000,000	+	+
10,000,000	+	+	3,500,000	–	+
15,000,000	–	+	6,600,000	–	+
20,000,000	–	+			
Boiled milk	–		Boiled milk	–	

tions with doses of around 500 r. Mazia (*18*) has shown that enzyme-substrate films are especially sensitive. Such experiments do, indeed, show that enzymes are extremely radiosensitive at very low concentrations. On the other hand, Scott (*19*) and Dunn (*9*) have shown that enzymes are extremely radioresistant when irradiated in their normal environment. This is to be expected since Barron (*20*), Forssberg (*21*), and Dale (*22*) have shown that radioresistance increases with increasing concentration and that very many compounds can protect enzymes in their natural environment by competing for the free radicals in solution. Remembering the role played by water, it is not surprising to find that dry, crystalline enzymes are very radioresistant (*23*). It is obvious that, while *in vitro* studies of dilute, highly purified enzymes can yield fruitful data on the mechanisms of radiation-inactivation, they are not very useful for predicting what will happen to an enzyme when irradiated in its natural environment.

The results that may be encountered in radiation-sterilization of enzyme-containing materials can be illustrated by data obtained from studies on raw milk (*24*). It was found that raw milk could be completely sterilized with 750,000 rep,* while 200,000 rep reduced the bacteria count by 99.7%. Under the same experimental conditions, the phosphatase test was positive in raw milk irradiated with 10,000,000 rep, but negative at 15,000,000 rep. The peroxidase test was positive at 1,000,000 rep, but negative at 3,500,000 rep. A later study (*25*) showed that irradiation of dried barley malt with 15,000,000 rep decreased the total diastatic activity of the malt by only 75%. These doses probably represent complete inactivation of the enzyme molecules as a whole, since Barron (*17*) has shown that some enzymes having oxidizable active groups can be reversibly inactivated by relatively low doses.

*rep = roentgen-equivalent-physical, the unit of cathode-ray dosage corresponding to the roentgen unit of X-ray dosage.

Destruction of Vitamins and Amino Acids

The effects of radiations on vitamins and amino acids show the same type of behavior. Studies on vitamins from the MIT group (*26–31*) show the effects of concentration and protection predicted by the activated water theory. Amino acids are easily destroyed by ionizing radiations in dilute solutions, but are practically unaffected in whole protein as it exists in its natural environment (*32, 33*).

Even so, the destruction of vitamins in foods at the sterilizing dose may be greater than by heat-sterilization. For example, a 50% destruction of riboflavin in milk and a 50% destruction of l-ascorbic acid in orange juice occurred at a sterilizing dose of 750,000 rep (*24*).

Irradiation of Frozen Materials

When radiation-sterilization is carried out at low temperatures, the chemical effects are reduced. This factor is associated more with the change in state at the freezing point rather than with a temperature effect *per se*.

In 1913, Duane and Scheur (*34*) investigated the effects of alpha rays on ice and found very little decomposition, while hydrogen and oxygen gases and hydrogen peroxide were readily produced in water. Svedberg and Brohult (*35*) found that haemocyanin and serum albumin when irradiated by ultraviolet light and alpha particles at room temperature were made inhomogeneous but that the same compounds when irradiated at the temperature of liquid air were protected. Several reports have appeared recently (*8, 30, 36*) showing the marked reduction of X-ray and cathode-ray-induced chemical reactions in the frozen state.

In the enzyme studies previously noted (*24*), irradiation of milk in the frozen state materially altered the effect of irradiation, as shown in Table 3. Even at the highest doses, there was still residual enzyme activity. To prevent thermal inactivation, it was necessary to cool the unfrozen controls and to fractionate the doses when very high doses were used since each 5,000,000 rep corresponds to a temperature rise of about 10° C. It was noted that 15,000,000 rep delivered to a cooled, but not frozen, sample of raw milk caused complete coagulation of the protein.

The protection of ascorbic acid in orange juice irradiated in the frozen state has been reported elsewhere (*30*).

In this connection, it might be mentioned that freezing has a very marked protective effect, even on relatively pure compounds in dilute solutions.

Flavor and Color Changes

Ionizing radiations can produce flavor and color changes. These changes are of the greatest importance to the food technologist because of the deleterious effects on his products.

Referring again to the studies on milk (*24*), even a "pasteurizing" dose of only 100,000 rep produced undesirable flavor changes. Larger doses caused a marked increase in the effect. Similarly, marked flavor changes occurred in skimmed milk at well below the sterilization dose. An off-flavor was produced in orange juice which, though not identical to that in milk, was still marked at 150,000 rep. On the other hand, the flavor of apple juice was not altered to any significant degree by doses as high as 1,000,000 rep, but a marked bleaching action on the apple juice was noted at doses as low as 300,000 rep.

The flavor and color changes were definitely minimized when the substances were irradiated in the frozen state, although the treated samples could still be readily distinguished from the controls.

The flavor changes present the greatest challenge to the chemist because they are due to compounds that are formed in amounts too small for detection by ordinary methods of analysis and in the presence of a variety of natural organic compounds. It is probably this difficulty of analysis that has discouraged any real attempt thus far to characterize and measure the compounds responsible for the off-flavors produced on irradiation.

Bactericidal Effect under Various Conditions

We have seen that undesirable chemical reactions are lessened as the material becomes more complex, that is, as the number of different reactive compounds increases. We have also noted almost complete elimination of such side reactions by freezing the material during irradiation. These results are in accord with the activated-solvent theory; that is, the protection is associated with competition of many different compounds for the destructive radicals and, also, with restriction of the mobility of those radicals in the frozen state.

One wonders if the bactericidal effect of ionizing radiations is lessened similarly under these conditions. The experimental evidence available today tends to indicate that no appreciable change in the sterilization dose is necessary. Although some studies on pure cultures of radiosensitive microorganisms indicate it is possible to alter their radiosensitivity by various chemical agents (*37*, *38*), it is found in practice that the 100% killing dose for the heterogeneous flora in most biological materials is not appreciably different.

Frozen milk requires about the same dose for sterilization as liquid milk (*24*). This is in accord with the "target" theory (*15*) which deals with the effects of ionizing radiations on microorganisms. According to this theory, a living cell is destroyed only if the ionizing particle passes through a definite sensitive volume within the cell. It is, then, a direct effect and is probably not associated to any great extent with the indirect effects that cause most of the chemical changes. However, it is just this direct action that requires exceptionally high doses for sterilization. Enough "bullets" must be fired randomly at the target so that every single microorganism will be hit. This requirement makes radiation-sterilization very inefficient indeed.

Indications for Irradiation in the Frozen State

It appears, then, that a requirement for efficient radiation-sterilization is that the material be irradiated in the frozen state. This will reduce the undesirable chemical effects while destroying the microorganisms present. It will not inactivate the enzymes, however. Such a procedure puts radiation-sterilization at a serious economic disadvantage for materials having a relatively low value per unit volume, although it may still be advantageous for such high-cost, low-volume materials as pharmaceuticals that cannot be heat-sterilized.

Recently, Meeker and Gross (*39*) of the Harvard Medical School reported the successful implantation of frozen, irradiated, aortic grafts in two humans. This report indicates a very promising area in which radiation-sterilization may be extremely valuable since, in such cases, no other satisfactory means of sterilization is available.

* * *

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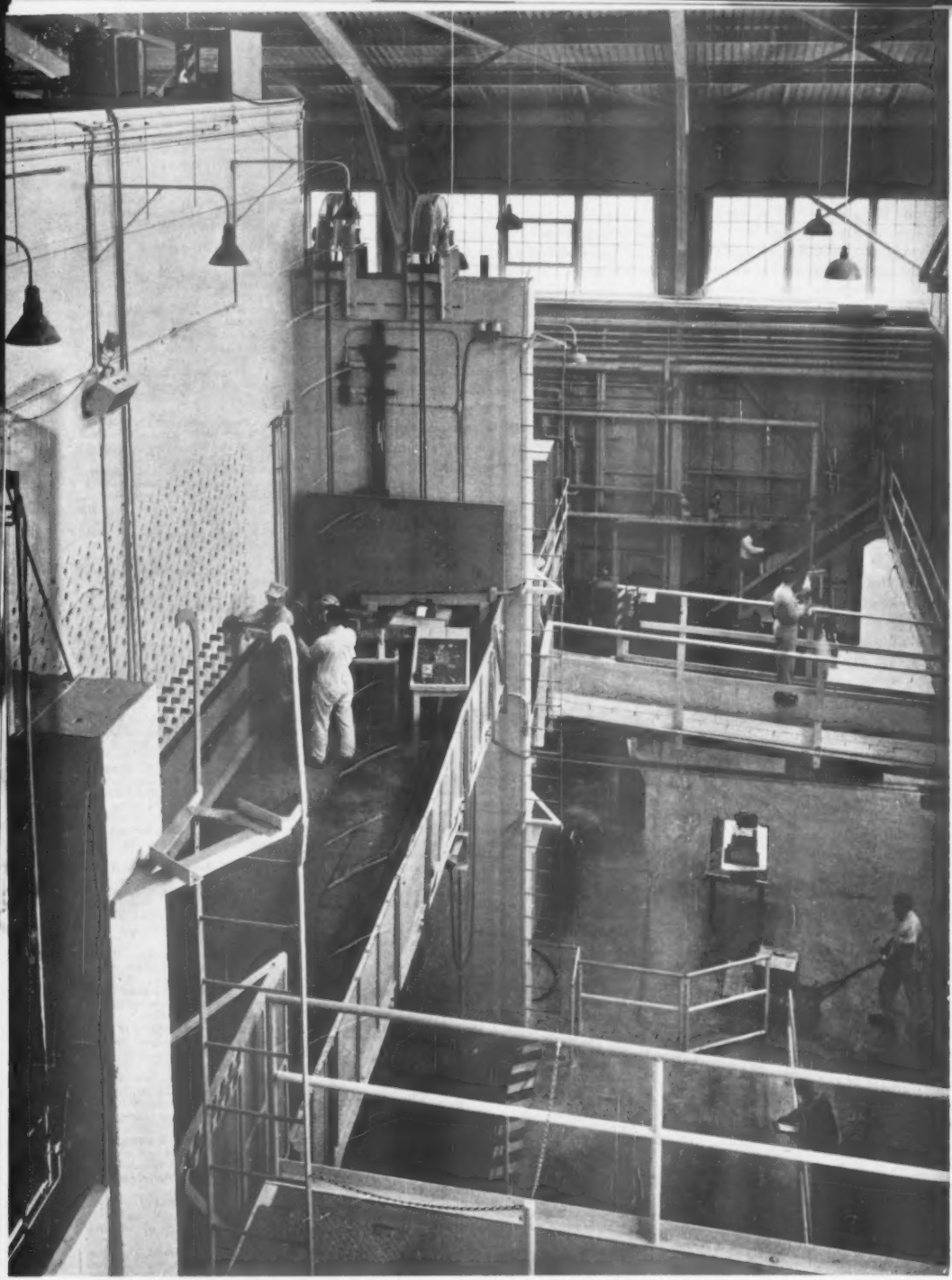
BIBLIOGRAPHY

1. F. Minck. Zur Frage über die Einwirkung der Röntgenschen Strahlen auf Bakterien und ihre eventuelle therapeutische Verwendbarkeit. *Münch. med. Wochschr.* **5**, 101 (1896)
2. B. E. Proctor, R. J. Van de Graaff, H. Fram. Research Report, U. S. Army Quartermaster Contract Projects, p. 217 (July 1942–June 1943), Dept. of Food Tech., MIT
3. A. Brasch, W. Huber. Ultrashort application time of penetrating electrons. *Science* **105**, 112 (1947)
4. Tenth Semiannual Report of the Atomic Energy Commission, pp. 98–99 (July, 1951)
5. Industrial uses of radioactive fission products, Report of Stanford Research Institute, Stanford, Calif. (Sept., 1951); also NUCLEONICS **8**, No. 5, 5 (1951), **9**, No. 2, 11 (1951), and **10**, No. 1, 45 (1952)
6. Anon. X-rayed milk stays fresh. *Science Digest* **30**, No. 3 (1951)
7. Anon. Cathode rays recommended for food, drug sterilization. *Chem. Eng. News* **22**, 2818 (1951)
8. A. Brasch, W. Huber. Reduction of undesirable by-effects in products treated by radiation. *Science* **108**, 536 (1948)
9. C. G. Dunn, W. L. Campbell, H. Fram, A. Hutchins. Biological and photochemical effects of high energy, electrostatically produced roentgen rays and cathode rays. *J. Applied Phys.* **19**, 605 (1948)
10. O. Risse. Die physikalischen Grundlagen der chemischen Wirkungen des Lichts und der Roentgenstrahlen. *Ergeb. Physiol.* **30**, 242 (1930)
11. J. Weiss. Radiochemistry of aqueous solutions. *Nature* **153**, 748 (1944)
12. M. Burton. Elementary processes in the radiation chemistry of water and implications for radiobiology. *Brit. J. Radiology* **24**, 416 (1951)
13. Symposium on "Radiation Chemistry and Photochemistry," University of Notre Dame, (1947)—see report in NUCLEONICS **1**, No. 2, 27 (1947); Colloquium on "Radiation Chemistry," Paris (1950); Symposium on "Radiation Chemistry," London (1950).
14. M. Burton. An introduction to radiation chemistry. *J. Chem. Education* **28**, 404 (1951)
15. D. E. Lea. "Actions of Radiations on Living Cells," (The Macmillan Co., New York, 1947)
16. "An International Bibliography on Atomic Energy, Vol. 2, Scientific Aspects," (Atomic Energy Commission Group, Department of Security Council Affairs, United Nations, New York, 1951)
17. E. S. G. Barron, S. Dickman. Studies on the mechanism of action of ionizing radiations. II. Inhibition of sulfhydryl enzymes by alpha, beta, and gamma rays. *J. Gen. Physiol.* **32**, 595 (1949)
18. D. Mazia, G. Blumenthal. Inactivation of enzyme-substrate films by small doses of X-rays. *Proc. Natl. Acad. Sci. U. S.* **34**, 328 (1948)
19. C. M. Scott. Some quantitative aspects of the biological action of X- and gamma rays. Great Britain Med. Res. Council, Special Report Series, No. 223, 99 (1937)
20. E. S. G. Barron, S. Dickman, J. A. Muntz, T. P. Singer. Studies on the mechanism of action of ionizing radiations. I. Inhibition of enzymes by X-rays. *J. Gen. Physiol.* **32**, 537 (1949)
21. A. Forssberg. Mechanism of the action of X-rays on enzymes in water solution. *Nature* **159**, 308 (1947)
22. W. M. Dale. Effect of X-rays on enzymes. *Biochem. J.* **34**, 1367 (1940)
23. D. E. Lea, K. M. Smith, B. Holmes, R. Merkham. Direct and indirect action of radiations on viruses and enzymes. *Parasitology* **36**, 110 (1944)
24. J. P. O'Meara. The effects of supervoltage cathode rays on fluid foods, S.B. and S.M. Thesis, Dept. of Food Technology, Massachusetts Institute of Technology (1949)
25. B. E. Proctor, J. P. O'Meara, unpublished data
26. S. A. Goldblith, B. E. Proctor. Effect of high voltage X-rays and cathode rays on vitamins (riboflavin and carotene). NUCLEONICS **5**, No. 2, 50 (1949)
27. S. A. Goldblith, B. E. Proctor, J. R. Hogness, W. H. Langham. The effect of cathode rays produced at 3000 kilovolts on niacin tagged with C^{14}. *J. Biol. Chem.* **179**, 1163 (1949)
28. B. E. Proctor, S. A. Goldblith. Effect of high-voltage X-rays and cathode rays on vitamins (niacin). NUCLEONICS **3**, No. 2, 32 (1948)
29. B. E. Proctor, S. A. Goldblith. Effect of soft X-rays on vitamins (niacin, riboflavin, and ascorbic acid). NUCLEONICS **5**, No. 3, 56 (1949)
30. B. E. Proctor, J. P. O'Meara. Effect of high-voltage cathode rays on ascorbic acid. *Ind. Eng. Chem.* **43**, 718 (1951)
31. P. C. Markakis, S. A. Goldblith, B. E. Proctor. Effect of ionizing radiations on vitamin B_{12}. NUCLEONICS **9**, No. 6, 71 (1951)
32. B. E. Proctor, D. S. Bhatia. Effect of high-voltage cathode rays on amino acids in fish muscle. *Food Technol.* **4**, 357 (1950)
33. D. S. Bhatia, B. E. Proctor. Effects of high-voltage cathode rays on aqueous solutions of histidine monohydrochloride. *Biochem. J.* **49**, 550 (1951)
34. W. Duane, O. Scheur. Decomposition of water by alpha-rays. *Radium* **10**, 33 (1913)
35. T. Svedberg, S. Brohult. Splitting of protein molecules by ultraviolet light and alpha rays. *Nature* **143**, 938 (1939)
36. G. Limperos, W. A. Mosher. Roentgen irradiation of desoxyribosenucleic acid. I. Mechanism of the action of irradiation in aqueous solution. *Am. J. Roentgenol. Radium Therapy* **63**, 681 (1950)
37. A. Hollaender, G. E. Stapleton, F. L. Martin. Effect of oxygen on response of living cells to X-rays with special emphasis on bacteria. *Federation Proc.* **9**, 61 (1950)
38. T. L. Thompson, R. B. Mefferd, O. Wyss. The protection of bacteria by pyruvate against radiation effects. *J. Bact.* **62**, 39 (1951)
39. I. A. Meeker, Jr., R. E. Gross. Low temperature sterilization of organic tissue by high-voltage cathode-ray irradiation. *Science* **114**, 283 (1951)



LOADING FACE of the graphite-moderated nuclear reactor at Oak Ridge National Laboratory is traversed by an elevating platform so that personnel can reach plugged-up openings to fuel channels to replace spent uranium slugs. A bundle of 10-ft lengths of light steel poles used to push slugs into place lies in brackets in front of the two men on the platform

FIRST STEP. Five-foot steel pipes filled with lead shot and paraffin are used to plug up holes in loading face. As one man withdraws plug, the other, wearing safety glasses, uses a rag to wipe off flecks of foreign matter that might be radioactive. Wires, tubes and other apparatus on wall are used in research

SECOND STEP. Aluminum-jacketed natural-uranium slugs are placed in opening on face. Each slug is 4 in. long, 1.1 in. in diameter, and weighs 2.57 lb. From 39 to 54 slugs are placed end-to-end in each channel. Opening in shield is round, but channel itself is diamond-shaped, allowing cooling air to flow past slugs

How to Load a Reactor

As natural uranium slugs in the 1,248 fuel channels of the reactor at Oak Ridge National Laboratory, Oak Ridge, Tennessee, are spent during fission, they must be replaced. The pictures show how this is done.

This reactor is a 24-ft cube of graphite blocks pierced by the fuel channels and by holes for isotope irradiation and research work. The fuel channels are diamond shaped, and cooling air is drawn through them at the rate of 100,000 ft^3/min, keeping the temperature of the uranium fuel below 245° C. The average temperature of the graphite moderator is 130° C.

The reactor was originally designed to operate at 1,000-kw capacity, but it now has a 3,800-kw power level.

The moderator, surrounded by an air space, is encased by a concrete shield 7 ft thick. The air space is 3 ft wide at the loading face, 6 ft wide at the opposite face. The shield structure itself is 47 ft long, 38 ft wide, and 32 ft high. It is sheltered by a barn-like corrugated-iron building.

Originally designed as a pilot plant for the large-scale plutonium production reactors at Hanford, Washington, the Oak Ridge reactor is now used for isotope production.

THIRD STEP. Steel rod is used to push slugs into place, with extensions added to the rod as necessary. Pushing in new slugs forces spent ones out the back of reactor. Highly radioactive, the spent slugs drop to an inclined neoprene pad, funnel into a chute, and are caught in a bucket shielded by a depth of 20 ft of water

CO_2 Ion-Chamber Techniques for Radiocarbon Measurement

One of the most sensitive methods for C^{14} detection and measurement is the use of an ionization chamber filled with radioactive CO_2. A basic review of the theory and techniques is given here

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CARBON-14 offers unlimited opportunities as a tracer isotope in biological, medical, and organic chemical research.

The long half-life of C^{14}, approximately 5,500 yr, is a convenience in that it eliminates the necessity of decay corrections and allows experiments to be conducted over long periods of time. However, the long half-life is a disadvantage in certain biological experiments, particularly those involving human patients, in that the total radiation dose of material fixed in the organism may become hazardous. Although recent experiments (*1, 2, 3*) have somewhat minimized this hazard, it is primarily for this reason that more sensitive detecting devices have been developed.

The soft beta ray emitted by C^{14} requires the use of special detection apparatus. At the present time there are three standard methods of measurement. In the first method, solid samples are measured with thin-window counters, internal counters, or ionization chambers. In the second, G-M or proportional counters are filled with active CO_2. In the third, ionization chambers are filled with active CO_2.

The efficiency of thin-window counters with barium carbonate samples is usually of the order of 5%, and approximately 0.3–0.4 millimole of carbon may be used in the sample.

G-M counters filled with a mixture of CO_2 and CS_2 have an efficiency of about 85%, and a sample of about 0.3–0.8 millimole of carbon may be used. A description of this method has been given in a previous report (*4*).

The primary advantage of the ionization chamber method with active CO_2 is that a much larger sample may be used. With the chamber now being used, as much as 11 millimoles of CO_2 may be measured.

Absolute specific-activity measurements of C^{14} are not readily made with an ionization chamber, but the chamber may be readily calibrated if a sample of known specific activity is available. In general, chamber measurements are reliable and consistent, so that only one calibration is necessary.

Ionization Chamber Theory

Radiation impinging on the gas filling of an ionization chamber results in the formation of positive and negative ions. This process, called ionization, is the basis of most radiation detection devices.

In an ionization chamber, the positive and negative ions are collected on two electrodes, called the cathode and anode, when an electric field is applied between these electrodes. If the radia-

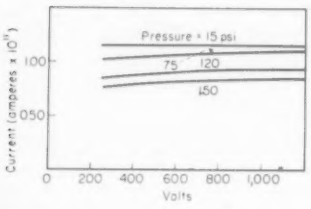

FIG. 1. Ionization current as a function of voltage and pressure

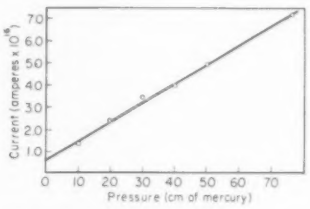

FIG. 2. Background ionization current as a function of pressure

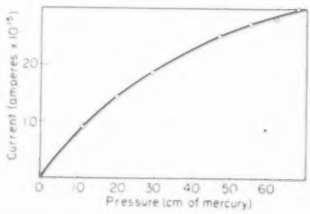

FIG. 3. Ionization current as a function of pressure for an activity of 13,500 dpm

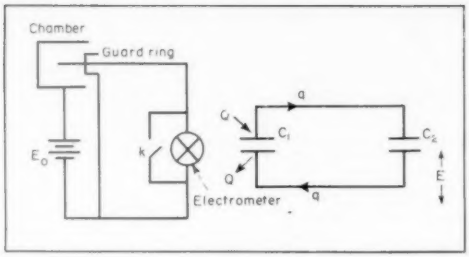

FIG. 4. Simple ionization-chamber circuit for rate-of-charge measurements

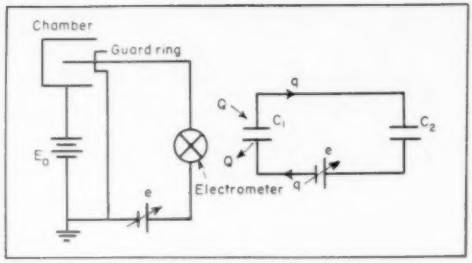

FIG. 5. Simple ionization-chamber circuit for null-reading measurements

tion level is constant, the collected ions produce a constant direct current at each electrode. By measuring this current, the intensity of the radiation may be determined and, in the present application, the amount of radioactive C^{14} within the chamber may be calculated.

The relation between the observed current and the amount of C^{14} in the chamber is a function of four quantities:

1. The average energy of the C^{14} beta-ray spectrum.
2. The average energy necessary for the production of one ion pair in CO_2.
3. The amount of radiation absorbed in the walls of the chamber.
4. The recombination of ionization within the chamber gas.

The average energy of the C^{14} spectrum is 0.050 Mev, based on maximum-energy measurements by Solomon (*5*).

Assuming the average energy for the production of one ion pair in air to be 32.5 ev, the average energy required for the production of one ion pair in CO_2 has been measured as 31.9 ev, and in argon, 27.8 ev.

Unfortunately, the third and fourth quantities are not readily measurable, and may be obtained only by the application of rather tenuous theory. This somewhat limits the chamber as a primary method of determining C^{14} absolute disintegration rates. However, other techniques are available which directly measure the absolute disintegration rate, and the chamber may readily be calibrated by introducing a known amount of activity and observing the resultant current. In general, the chamber and the current measuring devices are exceptionally stable and require only infrequent calibrations.

Figure 1 shows the variation of current as a function of pressure and voltage when a constant amount of activity is in the chamber. The chamber used in these measurements was designed to withstand rather considerable pressures and is somewhat larger than the chambers used for standard C^{14} analysis.

At atmospheric pressure, the variation of current with voltage is very slight, which indicates that very little or no recombination is occurring. At higher pressures, the current increases with increasing voltage, which indicates that in the pressure range above several atmospheres, recombination becomes an important factor. In general, it is felt that the usual chamber design will exhibit no recombination effects when operated below one atmosphere of CO_2.

Figure 2 shows the variation of background current with increasing pressure of CO_2 in the counter. The increase is seen to be linear over the pressure range studied. This agrees with the assumption that the background ionization caused by cosmic rays and local gamma rays per unit mass of gas is constant. The extrapolated current at zero pressure results from the ionization of the alpha-ray contamination of the chamber.

Figure 3 shows the variation of current with pressure from a chamber containing a constant amount of C^{14}. At low pressures, much of the ionization is lost in the walls of the chamber, but the current approaches a limiting value at high pressure. This limiting value of current corresponds to the collection of all ionization produced by the C^{14} radiation.

The optimum pressure for the measurement of a small CO_2 sample is actually a function of the activity. However, this optimum pressure is not critical, and for most measurements, a pressure of 50 cm of mercury is suitable.

The theory of collection of ionization within the ionization chamber is discussed at some length by Rossi (*6*) and Wilkinson (*7*). For further information on this topic, these texts are recommended.

Current-Measurement Theory*

In general, ionization currents are measured either by a rate-of-charge method or a high-resistance-leak method. In the former case, the voltage increase across a small capacitor is measured, and in the latter, the voltage drop across a high resistance is measured. A null method of reading may be used in either case.

Currents as small as 10^{-17} amperes may be measured by the rate-of-charge method if the insulators and electrometer circuit are properly designed. For measurement of currents of this magnitude, the insulation resistance of the center electrode of the chamber should be at least 10^{17} ohms. The limiting factor, however, is the thermal noise in the input circuit, which is comprised of the insulation resistance, stray capacity to ground, and the capacity of the electrometer itself. If an amplifier is used, as in the case of the vibrating-reed electrometer, the shot-effect noise of the input stage may be the limiting factor.

Currents greater than 10^{-15} amperes are most easily measured by the high-resistance-leak method because of the

* The derivation of circuit theory presented in this section is based on a paper by Dr. Francis R. Shonka at the Technical Conference of the Instrument Society of America, Chicago, Sept., 1947, and on the treatment of the theory of a radon chamber by Professor R. D. Evans (*8*).

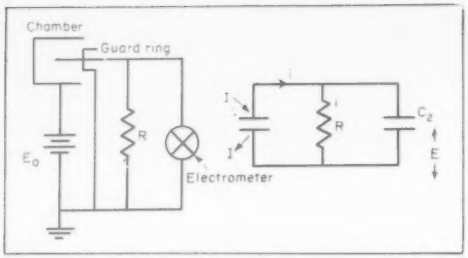

FIG. 6. Simple ionization-chamber circuit for leak-resistance measurements

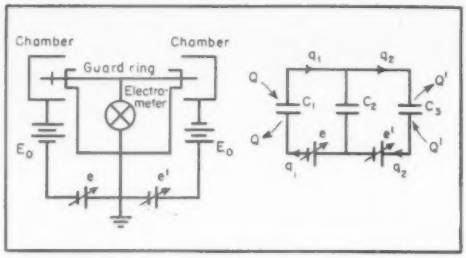

FIG. 7. A general ionization-chamber circuit for use with two ion chambers

absence of stray-capacitance effects. Resistances as large as 10^{13} ohms and calibrated to 1% may be readily obtained.

The simplest type of ionization-chamber circuit for rate-of-charge measurements consists of a chamber, an electrometer, and a shorting switch, as shown in Fig. 4. The guard ring is added to prevent leakage across the center-electrode insulator, and the battery provides the ion-collection voltage.

In Fig. 4, if the switch K is closed, the voltage across the chamber will be E_0; the charge on the chamber will be

$$Q_0 = E_0/C_{\text{chamber}}$$

If K is opened, the voltage will remain zero unless ion collection takes place in the chamber. In the following treatment, we shall not consider Q_0, but only the changes in charge, as these changes must satisfy Kirchoff's second law.

The circuit may be represented schematically by two capacitances, C_1 and C_2, the capacitance between the center and outer electrodes of the chamber, and the capacitance between the center electrode and ground, respectively. The direction of the arrows in Fig. 4 indicate the conventional flow of charge rather than electronic flow.

If a collecting potential is applied across the chamber, the positive and negative ions will be attracted to the electrode of opposite potential. This ionic flow can be represented by a charge, Q, flowing onto one plate of C_1 and an equal charge flowing from the other. It is important to note that this charge flows only in C_1. Because of this dislocation of charge in C_1, a charge, q, flows in the circuit. By Kirchoff's second law

$$[(Q - q)/C_1] - q/C_2 = 0$$

and

$$Q = q\,[(C_1 + C_2)/C_2]$$

The voltage, E, measured by the electrometer is q/C_2. Thus

$$E = Q/(C_1 + C_2)$$

The sensitivity, S, of the system is

$$S = \frac{\partial E}{\partial Q} = \frac{1}{C_1 + C_2}$$

In the usual measurement, the length of time necessary for E to increase a given amount is recorded. From this, the ionization current, I, can be found from

$$I = \frac{\Delta Q}{\Delta t} = (C_1 + C_2)\frac{\Delta E}{\Delta t}$$

By adding a variable voltage source, e, we can change our circuit to a null-reading circuit. This is shown in Fig. 5. In this case

$$\frac{Q - q}{C_1} - \frac{q}{C_2} + e = 0$$

and

$$Q = E(C_1 + C_2) - eC_1$$

$$E = \frac{Q}{C_1 + C_2} + \frac{eC_1}{C_1 + C_2}$$

We vary e until E is zero. Then

$$Q = -eC_1$$

If we define the sensitivity as $(\partial E/\partial Q)_{e=\text{const}}$, we find that the value is the same as in the previous case

$$S = 1/(C_1 + C_2)$$

Although this method of measurement has the same sensitivity as the simpler case, it possesses some advantage in that the voltage across the electrometer is zero, which eliminates some leakage current, and in that the null method of reading is somewhat more accurate.

If we add a high resistance to our simple circuit, we can measure currents by the leak-resistance method (Fig. 6). In this case, Q is replaced by I, and q by i. For a steady-state solution, I will be constant as the production and collection of ions is constant. It is then obvious that $I = i$ and the measured voltage, E, is

$$E = IR$$

This measurement is independent of any capacitance, and is more convenient if currents greater than 10^{-15} amperes are to be measured. Leak resistances may be added to any of the more complicated circuits which will be discussed.

Let us consider a more general type of circuit which we can use to describe most special ionization-chamber circuits. In Fig. 7 we have two chambers with charge flow of Q and Q' and two balancing voltages, e and e'. The polarity of E'_0 may be chosen so that the charge flow Q' can be added to Q or subtracted from Q as in differential or balance chambers. The voltage across the electrometer is

$$E = (q_1 - q_2)/C_2$$

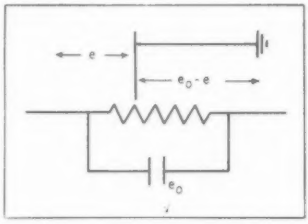

FIG. 8. Potentials of a bridge circuit at null reading

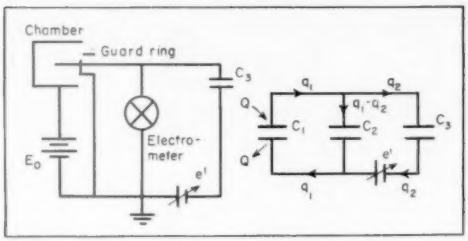

FIG. 9. Ionization-chamber circuit modification for vibrating-reed electrometer

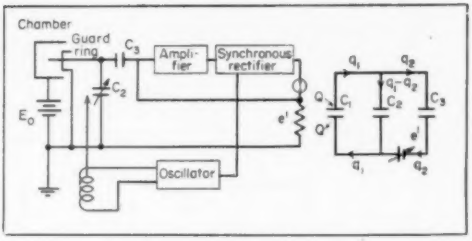

FIG. 10. Block diagram and analogous circuit of vibrating-reed electrometer

By Kirchoff's second law we have

$$\frac{Q - q_1}{C_1} - \frac{q_1 - q_2}{C_2} + e = 0$$

$$\frac{q_1 - q_2}{C_2} - \frac{Q' - q_2}{C_3} + e' = 0$$

Solving for q_1 and q_2 we get

$$q_1 = \frac{1}{C_1 + C_2 + C_3} \times \{C_1Q' + (C_2 + C_3)Q + C_1C_3e' + C_1(C_2 + C_3)e\}$$

$$q_2 = \frac{1}{C_1 + C_2 + C_3} \times \{(C_1 + C_2)Q' + C_3Q + C_3(C_1 + C_2)e' + C_1C_3e\}$$

The solution for E is

$$E = \frac{1}{C_1 + C_2 + C_3} \times (Q - Q' + C_1e - C_3e')$$

If we set E equal to zero we get

$$(Q - Q') = C_3e' - C_1e$$

We shall define the sensitivity, S, as

$$S = \left(\frac{\partial E}{\partial (Q - Q')}\right)_{e,\,e'\,\text{constant}} = \frac{1}{C_1 + C_2 + C_3}$$

The sensitivity is decreased by the addition of the factor C_3. However, this loss is more than offset by the added advantages of modifications of this circuit.

One modification of this circuit involves a bridge circuit or potentiometer to supply the voltages e and e'. The bridge circuit is adjusted to give a null reading, and from the value of e, the difference between the two currents can be determined (Fig. 8).

In this case

$$e = e$$

$$e' = e_0 - e$$

Substituting these relations in the above results we get

$$(Q - Q') = e_0C_3 - e(C_1 + C_3)$$

when E is zero. The sensitivity of the circuit remains the same. This expression is convenient in that C_2, the capacity of the collecting electrode and electrometer to ground, does not appear. In most applications, the two chambers would be identical and C_1 would equal C_3.

The second modification of this circuit (Fig. 9) is very useful in practice and is incorporated in the vibrating-reed electrometer. The second chamber is replaced by a feedback capacitor, C_3, and the voltage, e, is usually zero. In the results of the analysis of the general circuit, we place Q' and e equal to zero. We then have

$$Q = E(C_1 + C_2 + C_3) + e'C_3$$

If we adjust e' so that E is zero, then

$$Q = e'C_3$$

The measurement of Q is independent of either C_1 or C_2. By means of this circuit, we can calibrate a meter to read directly the charge flow, Q, from any chamber. The sensitivity is the same as that of the general circuit.

To illustrate the usefulness of the last modification, the circuit of the vibrating-reed electrometer will be discussed. The singular feature of the vibrating-reed electrometer is the use of an alternating-current amplifier to maintain the circuit constantly at the null point. Any voltage, E, appearing across the vibrating reed, which corresponds to the electrometer in previous diagrams, results in an a-c voltage of the same frequency as the mechanical frequency of the reed, but with a phase sensitive to the polarity of the voltage, E. This a-c voltage is amplified, synchronously rectified, and fed back into the input circuit as e', whose polarity is opposite to E. A block diagram and an analogous circuit diagram are shown in Fig. 10.

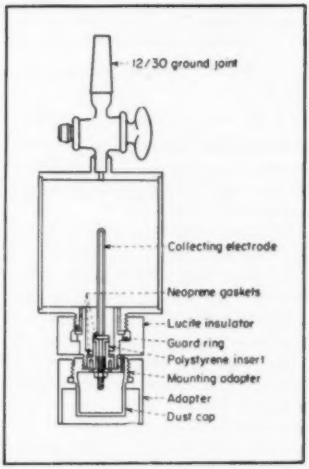

FIG. 11. Design of gas ionization chamber. Mirror finish on all inside surfaces. All parts brass unless otherwise specified

In this circuit, the capacitance C_2 consists of a constant component, C_0, including the stray capacitance to ground, and an alternating component that results from the motion of one plate of the vibrating-reed capacitor. The reed is maintained in oscillation by a magnet driven by an oscillator. Thus

$$C_2 = C_0 + C\cos\omega t$$

Therefore

$$E = \frac{q_1 - q_2}{C_0 + C\cos\omega t}$$

Thus, if a charge, $q_1 - q_2$, is placed on the capacitor, an alternating voltage proportional to that charge is produced. This voltage is then amplified,

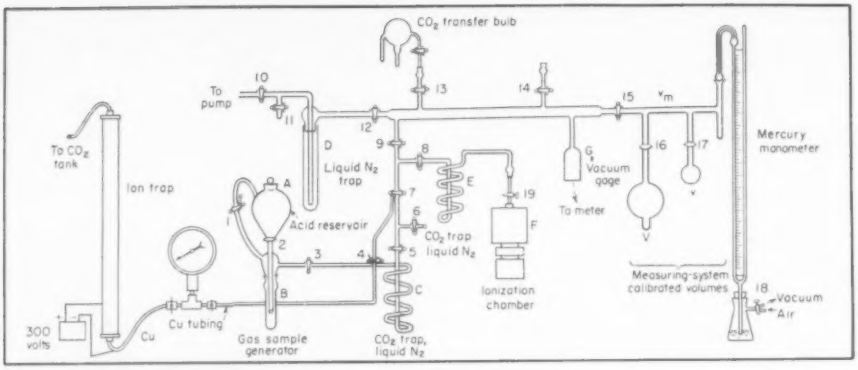

FIG. 12. Evolution and filling line for CO_2 samples

synchronously rectified so that the voltage e is opposite in polarity to E, and is fed back into the input circuit through the capacitance C_3.

As in any negative feedback circuit, the feedback cannot be 100%, and the circuit cannot be exactly nulled. However, the amplification is about a factor of 200, and so the voltage E is maintained at about 1/200th of e'. In most cases, the calculations can be performed as though the circuit were actually nulled. This can be expressed analytically as follows.

From the theory of the general circuit

$$Q = E(C_1 + C_2 + C_3) + e'C_3$$

and

$$e' = AE$$

where A is the amplification. Thus

$$Q = e' \left\{ \frac{C_1 + C_2 + C_3}{A} + C_3 \right\}$$

If C_1 and C_2 are comparable to C_3, about 10^{-11} farads, the first term in the brackets may be neglected. Then

$$Q = e'C_3$$

This is the result we would have obtained if the circuit had been perfectly nulled. In other words, the term which was neglected resulted from the fact that the circuit was not entirely nulled.

Ionization-Chamber Design

The basic design of an ionization chamber is relatively free from difficulties. Almost any dimensions and shapes may be used, provided the electric field does not exceed the value required to produce ionization at any point in the chamber. The simplest design that fulfills this requirement is a cylindrical chamber with a center rod of fairly large diameter.

The most critical design consideration is that of the center-rod insulator. In general the limitation is not a question of suitable resistance, since many materials have suitable insulating properties if the ambient humidity is maintained at a reasonable level. However, the problem of stress currents is one that still has not been solved to complete satisfaction. Stress currents appear across an insulator after it has received either electrical or mechanical stress. These currents appear to die away with a half-time of the order of 15–20 min, and the magnitude of this current depends upon the type and duration of stress. Presumably, stress currents result from actual translation of charge within the insulator as the mechanical stress is relieved. The following design features appear to be useful in reducing the magnitude of stress currents:

1. The volume of the insulator should be kept to a minimum.

2. The areas of contact between insulator and metal should be minimal, and the contact should be positive, i.e., the insulator should not be wedged between metal supports. (In certain applications involving high-pressure chambers, it is necessary to use a wedge insulator to provide mechanical strength. In these applications, it is usually not necessary to change the pressure.)

3. Polystyrene and Teflon appear to be equivalent in regard to stress current.

4. Since the primary source of stress currents is the evacuation of chambers, evacuation and refilling should be completed as rapidly as possible.

5. A grounding cap should be provided to prevent the center rod from acquiring static charges when the chamber is not connected to the electrometer.

A practical solution to the problem of stress currents is to allow the chambers to rest for a half hour, or more, between filling and the measurement of the ionization current.

The chamber used in this research is based on the design of C. J. Borkowski of Oak Ridge National Laboratory, and is used routinely at that laboratory. The design of this chamber is shown in Fig. 11.

The volume of the chamber is 250 cm^3, and a collection voltage of 300 volts is routinely used. The insulator is of commercial Amphenol design made of molded polystyrene. Machined Teflon insulators have also been used.

An important consideration in chamber design is a low alpha background from naturally radioactive materials in the wall. Careful selection of wall material is one solution to this problem as indicated by the measurement of Bearden on various wall materials (9). However, this method is usually not convenient, as large variations might occur even with a given construction material. Careful cleaning of the inner surfaces appears to help, but the method which appears to give the

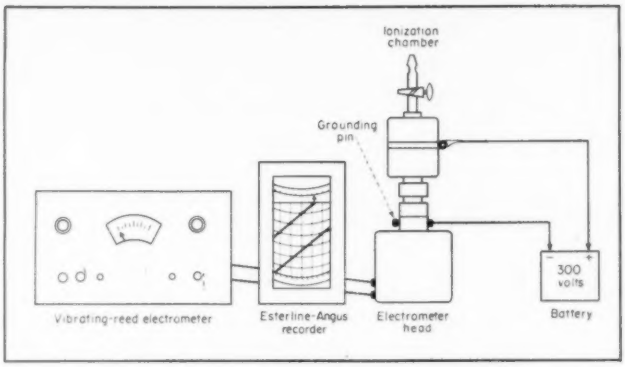

FIG. 13. Set-up of vibrating-reed electrometer and ionization chamber

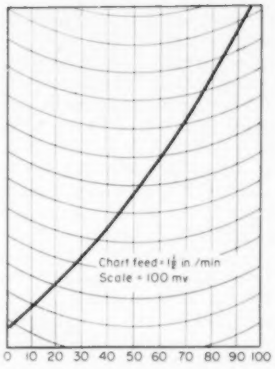

FIG. 14. Typical chart reading

best results is to coat the surface with a material of low alpha contamination. A heavy coat of silver paint* appears to be useful in this regard.

There are several types of chambers available that can be used in the routine measurement of C^{11}. These are described in detail in the papers by Henriques (*10*), Janney (*11*), and Jesse (*12*).

Evacuating and Filling System

The system for evacuating and filling the chambers consists of an ion trap, a vacuum line, and a pumping system (Fig. 12).

The tank CO_2 which is used to fill the chambers to the standard pressure (50 cm Hg) contains small amounts of heavy organic molecules which cause a spurious current on being introduced into the chamber. These heavy molecules and ions may be removed by passing the gas through a stainless-steel filter and an ion trap (*13*).

The vacuum line provides a rapid and quantitative means of evolving, transferring, storing, and diluting the CO_2, in addition to evacuating and filling the chamber.

Attached to the manifold (the main artery of the vacuum system) are two pumps, a mechanical pump and a mercury diffusion pump.

Evolution of CO_2 from $BaCO_3$

The CO_2 may be evolved from the $BaCO_3$ in either of two ways. The first method is that used in the filling of gas counters with CO_2 (*4*); the second method is by acidification with concentrated sulfuric acid under vacuum.

The barium carbonate sample is weighed and placed in reaction flask B (see Fig. 13) which is attached to the vacuum system after greasing the lip of the flask with a small amount of silicone grease (Dow-Corning High-Vacuum Silicone Lubricant). Concentrated sulfuric acid is placed in reservoir A and a vacuum is obtained in the reservoir, sidearm, B and C and up to stopcock No. 5. Then stopcock No. 3 is closed and acid is added dropwise until the evolution of CO_2 is completed and there are no more bubbles formed in B.

The evolved CO_2 is trapped in spiral C by placing liquid nitrogen around the spiral and slowly opening stopcock No. 3. Once the CO_2 is distilled over into C, the vacuum is checked in the system from stopcock No. 3 through to Nos. 8 and 9.

At this time, if there is any need for a check on the quantitative evolution of CO_2 from the sample, the pressure may be measured in the calibrated volumes V, v and v_m. In this case

$$\text{millimoles } BaCO_3 = \frac{\text{volume used}}{22.4} \times \frac{\text{cm Hg}}{76} \times \frac{273.2^\circ\text{ C}}{T + 273.2^\circ\text{ C}}$$

where T is the room temperature. The percent efficiency of evolution is given by

$$\frac{\text{millimoles } BaCO_3 \times 197.4}{\text{weight of } BaCO_3}$$

If the weight of sample is unknown, the calibrated volumes may be used to determine the weight of the original sample by assuming 100% efficiency of evolution.

Filling the Chamber

The ionization chamber may be filled by allowing the radioactive CO_2 to diffuse into the chamber from a small liquid-nitrogen trap, or by sweeping the radioactive CO_2 into the chamber with inert CO_2. The first method requires the condensation of rather large amounts of CO_2 in a small trap, but this method must be used if the active sample is so large that only a small amount of inert CO_2 is required to bring the chamber pressure to the desired value.

Sweep method. The chamber is placed on the vacuum line and evacuated by opening stopcock No. 19 back to the pump. When the vacuum is complete, stopcocks Nos. 9 and 19 are closed and the CO_2 which has been trapped in coil C is distilled over into coil E by removing the liquid nitrogen from C and placing it around E. The gas in C may be brought to room temperature more quickly by placing it in a beaker containing warm water. Stopcock No. 8 is then closed and the liquid nitrogen is removed from E. Then the line is evacuated from stopcock No. 4 on through to the mercury manometer while the calibrated volumes beyond points 16 and 17 remain closed. Tank CO_2 is flushed slowly through stopcock No. 4 (two-way stopcock) into the room for two minutes to remove any air out of the line to the tank. Then the tank CO_2 is very slowly introduced into the vacuum line through stopcock No. 4 while the

* Silver paint No. 4817, E. I. duPont de Nemours and Co., Inc., Electrochemical Department, Perth Amboy, N. J.

line to the pump beyond stopcock No. 12 remains closed.

When the mercury manometer indicates that the entering CO_2 is exerting a pressure greater than the expected pressure that the evolved CO_2 will exert in the chamber, stopcocks Nos. 8 and 19 are opened. The evolved radioactive CO_2 is pushed into the chamber by the greater pressure of the inert tank CO_2. (The pressure in the manometer will drop momentarily when the stopcocks are opened.) Care should be taken so that when the proper pressure (50 cm Hg) of inert and radioactive CO_2 in the chamber is obtained, stopcock No. 19 is closed quickly and then stopcock No. 4 is closed. The chamber is then removed from the system and is ready to be mounted on the vibrating reed.

Expansion method. This method is similar to the diffusion method, up to and including the transfer of gas from coil *C* to coil *E*. The stopcock to the chamber (No. 19) is opened and stopcock No. 8 is closed. The CO_2 in *E* is allowed to come to room temperature and thus expand into the chamber.

When the expansion is complete (there is no evidence of any solid CO_2 remaining in *E*), the chamber is closed and the line is evacuated from stopcock No. 19 back to the pump. Some of the evolved radioactive CO_2 is discarded in this method. Since the volume of the chamber is known, the aliquot of the original sample that is in the chamber is known. The chamber is filled to 50 cm Hg pressure in the same manner as in the diffusion method.

Measuring the Activity

The chamber, after it has been filled to the normal operating pressure, is placed on the head of the vibrating reed* and attached by three screws.

A 300-volt battery is connected to supply the collecting voltage. The positive terminal of the battery is the outer cylinder of the ionization chamber, while the negative terminal is connected to the head of the vibrating reed (Fig. 13).

A minimum period of 30 min is allowed to elapse before any measurements are made. This waiting period is necessary to allow the initial electrical and mechanical stress currents within the insulator to be reduced to a negligible value. At the end of this waiting period the chamber operates satisfactorily.

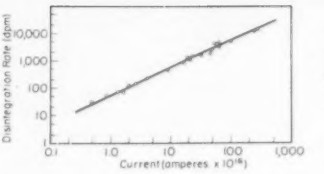

FIG. 15. Activity as a function of ionization current for a pressure of 50 cm Hg

The actual operation starts when the contact switch is ungrounded carefully, and the ionization current is collected and measured by the rate-of-drift method. The current is measured by recording the rate of drift on an Esterline-Angus recorder,† that is, the time necessary for the needle to indicate a drift of 0–10, 0–100, or 0–1,000 mv, depending on the activity of the sample (Fig. 14). The reading is normally recorded as the number of divisions traveled by the needle to go, for example, from 0 to 100 mv.

A background reading (unshielded) was made on a small chamber used in this laboratory. The driving gear on the recorder had 60 teeth, and the driven gear had 30 teeth. The recorder was run at slow speed, which feeds the chart through at a rate of 6 in., or 12 divisions, per hour; four readings averaged 8.40 divisions.

To find the current in amperes, the number of millivolts is multiplied by a factor, *k*, and divided by the ratio of the number of divisions in the reading to the number of divisions per minute. The factor *k* includes the appropriate conversion factors for the units used and the capacitance of the feedback capacitor of the vibrating-reed electrometer. In this case

$$k = \frac{12.5 \times 10^{-12}\ \text{(farads)}}{1{,}000\left(\frac{\text{mv}}{\text{volt}}\right) \times 60\left(\frac{\text{sec}}{\text{min}}\right)} = 2.08 \times 10^{-16}$$

Thus, the background current found was

$$\frac{100}{8.40} \times 2.08 \times 10^{-16} \Big/ \frac{12}{60} = 4.95 \times 10^{-16}\ \text{amperes}$$

Now if the amount of $C^{14}O_2$ which was contained in the chamber exerted a pressure of 13.06 cm Hg in a volume of 261.8 cm³ (the volume in the manometric system) at 27.9° C, we then have

$$\frac{261.8}{22.4} \times \frac{13.06}{76} \times \frac{273.2}{301.1} = 1.821$$

millimoles of $C^{14}O_2$ in the chamber.

The reading on the vibrating reed was 26.9 divisions at 60/30 fast speed, which is equivalent to 6 in., or 12 divisions, per minute. One hundred millivolts were collected. Thus, the current was

$$\frac{100}{\frac{26.9}{12}} \times 2.08 \times 10^{-16} = 9.29 \times 10^{-15}\ \text{amperes}$$

Subtraction of the background reading gives 8.79×10^{-15} amperes.

Now the total sample of $C^{14}O_2$ evolved was 6.20 millimoles. Thus

$$\frac{8.79 \times 10^{-15}}{1.821} = \frac{X}{6.20}$$

and $X = 2.99 \times 10^{-14}$ amperes, the current for the complete C^{14} sample.

The chamber was previously calibrated with a standard C^{14} sample whose absolute disintegration rate is known. Thus, the equivalent number of disintegrations per minute, or microcuries of C^{14}, can be read directly from a graph or chart (Fig. 15).

* * *

This development program was carried out under the direction of Professor Robley D. Evans.

BIBLIOGRAPHY

1. H. E. Skipper, L. White, Jr., C. E. Bryan, *Science* **110,** 306 (1949)
2. H. E. Skipper, L. White, Jr., C. E. Bryan, *J. Biol. Chem.* **180,** 1187 (1949)
3. H. E. Skipper, M. J. Bell, J. B. Chapman, *Cancer Research* **10,** 362 (1950)
4. G. L. Brownell, H. S. Lockhart, CO_2 counter techniques for C^{14} measurement, Technical Report No. 30 (Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Mass., 1949)
5. A. K. Solomon, R. G. Gould, C. B. Anfinsen, *Phys. Rev.* **72,** 1097 (1947)
6. B. B. Rossi, H. H. Staub, "Ionization Chambers and Counters," National Nuclear Energy Series V-2 (McGraw-Hill Book Co., Inc., New York, 1949)
7. D. H. Wilkinson, "Ionization Chambers and Counters" (Cambridge University Press, Cambridge, England, 1950)
8. R. D. Evans, Apparatus for the determination of minute quantities of radium, radon, and thoron in solids, liquids, and gases, *Rev. Sci. Instr.* **6,** 99 (1935)
9. T. A. Bearden, *Rev. Sci. Instr.* **4,** 271 (1933)
10. F. C. Henriques, Jr., C. Marghetti, *Ind. Eng. Chem., Anal. Ed.* **18,** 417 (1946)
11. C. D. Janney, B. J. Moyer, *Rev. Sci. Instr.* **19,** 667 (1948)
12. W. P. Jesse, L. A. Hannum, H. Forstat, A. L. Hart, *Phys. Rev.* **71,** 478 (1947)
13. R. D. Evans, *Rev. Sci. Instr.* **4,** 223 (1933)

* Vibrating Reed Electrometer, Argonne National Laboratory model.

† Esterline-Angus Graphic Ammeter.

Analysis of Urine for Gross Radioactivity

A urinalysis using the adaptations of the direct-evaporation method described here can provide a quick estimate of the possible seriousness of entry of radioactive substances into a worker's body during a contamination accident

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RADIOASSAY OF URINE as a method of estimating the body burden of a particular radioactive substance or group of substances has been widely developed in recent years.

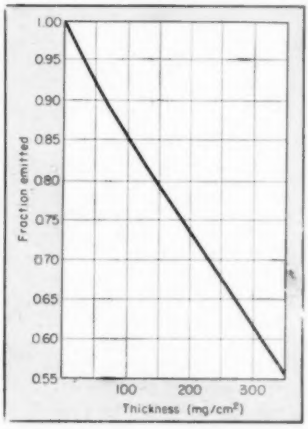
Generally, attention has been directed toward the relatively slow elimination of material firmly fixed in the body. To detect the presence of an amount well below that considered permissible, it has been necessary to use samples taken over a 24-hour period in connection with chemical separation techniques of some complexity.

When a radioactive substance is first taken into the body, there is a period of days or weeks, prior to the setting up of the situation referred to above, during which there is much more copious urinary elimination. It seemed reasonable to assume that this rapid initial rate of elimination could be used to evaluate roughly the seriousness of cases of accidental ingestion, inhalation, or absorption of radioactive substances.

The methods described here were developed with this objective, the intent being to use relatively small samples and simple processing techniques and to detect a wide variety of substances.

Direct-Evaporation Method

The simplest method of radioassay of urine is to evaporate a sample to dryness and count the residue. There exists the inclination to dismiss this method as useless because of two factors seriously limiting the sensitivity. The first is the considerable K^{40} activity, always present in urine, that will tend to mask the presence of small amounts of radioactive substances for which one is looking. The second is the large content of solids that will result in self-absorption of beta particles by the residue to be counted and place an upper limit on the size of sample that can be profitably evaporated.



SELF-ABSORPTION of K^{40} beta particles by evaporated urine

They are indeed important limitations but do not in practice mean that the method is entirely useless. Let us consider these limitations quantitatively and look at some examples of the practicability of the direct-evaporation method.

Limitation imposed by potassium content. Naturally occurring potassium gives off 28.3 ± 1.0 beta particles per gram per second (*1*) because of the radioisotope K^{40} that has a relative abundance of 0.011%. A smaller number of gamma rays (12.7 per 100 betas) are emitted but their effect on urinalysis is ordinarily negligible because of the low efficiency of Geiger-Müller tubes for gamma-ray counting. Since the composition of urine varies

widely from individual to individual, and from day to day for a particular person, a random collection of samples was used; 150 cm³ from each sample were evaporated and a portion of the solid residue counted. In this way, it was possible to get an idea of the range of K^{40} activity to be expected for uncontaminated individuals.

The average for 30 analyses was 94 disintegrations per minute per gram of solids, the values being distributed between 32 and 192 dpm/gm. It was found that, because of the very wide variations in solids content, it was desirable to express the K^{40} activity per gram of solids. When expressed as activity in a certain volume of urine, a much wider spread of values was obtained.

It is recognized that 30 individuals constitute a relatively small sample and that the K^{40} activity at other seasons of the year and for other sections of the country might be considerably different from that noted. However, the values obtained have been useful as a guide for interpretation of a number of samples assayed by simple evaporation.

In determining the K^{40} activity of urine, the 150-cm³ samples were evaporated to dryness at 80° C on a hot plate located in a fume hood. This method minimizes loss of volatile components and the entrainment that may occur with boiling. The evaporation rate was about 50 cm³/hr. The final stages of evaporation were done at reduced temperature to avoid charring of the residue. An infrared lamp can also be used for the latter stage.

After evaporation, a portion of the dry residue was mounted on a planchet and counted with the usual thin end-window G-M tube.

Allowance for self-absorption was made from the curve shown on page 33. It was obtained as follows: An imaginary sample of X mg/cm² weight was divided, for purposes of computation, into zones of thickness corresponding to 10 mg/cm². For each zone, the average absorption between it and the surface was noted, and reference was made to the beta-particle energy necessary to penetrate just to the surface. A spectral distribution curve for K^{40} (*2*) was then used to determine the fraction of beta particles from the zone in question that reached the surface. This was done by measuring the fraction of the area under the curve lying above the energy noted. Results for all zones were averaged for the value of X.

While not entirely rigorous, this method seems to have merit when experimental determination of self-absorption cannot be made conveniently.

The limitation imposed by K^{40} content may be illustrated by considering a typical sample containing K^{40} activity of 94 dpm/gm of solids and a total weight of solids of 1.6 gm corresponding to 50 cm³ of urine. The sample will contain a total activity of 150 dpm of K^{40}. A 1-day elimination, arbitrarily taken as 1,200 cm³, will contain 3,600 dpm. On this same basis, 192 dpm/gm would correspond to a 24-hr elimination rate of 7,350 dpm, whereas 32 dpm/gm would correspond to 1,230 dpm. If this spread in values is accepted, we see that the uncertainty in K^{40} dpm can mask the presence of spurious activity being excreted at the rate of about 6,000 dpm/day by an individual about whose K elimination nothing is known.

Limitations imposed by the solids content. Because of the solids present in urine, the size of sample that can be counted after direct evaporation is limited. The severity of this limitation depends on the energy of the beta rays emitted by the contaminant in question. Even for energies in the vicinity of 1 Mev, a 50-cm² sample is about as large as can be accommodated without an undesirably large correction for self-absorption.

In practice, it is well to count the residue from a 25 to 50-cm³ sample but, when interpreting the results, one must bear in mind the fact that soft components will be detected at low efficiency.

Utilization of Method

In laboratories where large quantities of radioactive substances are manipulated, it is inevitable that unplanned radioactive contamination of laboratory air, bench tops, and floors, as well as of personnel, will occur. In a well-managed laboratory, safeguards are established to prevent such "spills," as they are often called, or, where prevention fails, to detect them before actual injury to workers results.

The direct-evaporation method of urinalysis, applied to the initial elimination after an incident, is a convenient way to find out whether an appreciable amount of a radioactive substance has been taken into the worker's body.

TABLE 1—Assay of Urine Samples after Fission-Product-Contamination Incident

Day	*Solids counted (grams)*	*Observed activity (cpm)*	*Average K^{40} (cpm)*
1	2.40	103 ± 4	17
3	1.87	6 ± 2	15
4	1.92	6 ± 2	15

The practicability of the method is perhaps best demonstrated by citing some examples of its use.

In research with mixed fission products, a technician worked without gloves for a few minutes and got his hands grossly contaminated. By the time a routine hand-and-foot-counter check was made and the assistance of a health physicist was sought, contamination had spread to his hair, face, moustache, shirt, and pants. A reasonably complete decontamination job was carried out in cooperation with the laboratory clinic.

Urine samples were collected since there was a possibility that activity had penetrated the skin, gotten into the mouth or been inhaled. The results obtained by direct evaporation of samples taken from the 24-hour urinary excretion for the first, third, and fourth day after the incident are given in Table 1. The average K^{40} cpm values were deduced from the value given above, i.e., 94 dpm/gm.

The activity found in the first day's sample was found to be decaying with a half-life of about 7 days. The observed count of 103 corresponds to a total elimination on the first day of roughly 20,000 dpm. This is a sizable rate of elimination, but it was not considered to be serious for several reasons: First, previous experience with a case of inhaled strontium (*3*), the most hazardous constituent of mixed fission products, indicated that a level such as this on the first day would result in negligible permanent deposition, even if only strontium were involved. Second, many substances less toxic than strontium are present in mixed fission products. Third, the effective half-life of 7 days showed that

TABLE 2—Assay of Urine Samples after Air-Contamination Incident

Solids in 50 cm³ (grams)	*Solids counted (grams)*	*Net cpm*	*dpm/gm*
1.75	0.71	3.7 ± 2.0	32 ± 18
2.32	1.10	7.8 ± 2.2	50 ± 14
3.67	1.70	11.5 ± 2.2	36 ± 7
1.67	0.63	7.6 ± 2.2	90 ± 26
3.35	1.58	12.5 ± 2.3	52 ± 9
2.18	1.33	12.9 ± 2.2	55 ± 9
3.80	1.56	9.7 ± 2.2	34 ± 8

relatively young fission products of a less toxic nature were involved.

It should be noted that, to be effective, collection of urine for this type of analysis should be started immediately after the incident. By the third and fourth days, in the incident noted, the rate of elimination of activity had already dropped to a point where it was not detectable by this method.

During initial adjustment of the pneumatic tubes used to place samples in the Brookhaven reactor, the air of the reactor building became contaminated. Personnel exposure was minimized by prompt evacuation of the area, but small amounts of activity were detectable on nasal smears taken from seven individuals. As a precautionary measure, 50-cm³ urine samples from the first 24-hour elimination were evaporated and counted with the results shown in Table 2.

As noted above, the range of values of K^{40} activity of solids is 32 to 192 dpm/gm. We concluded from this that absorption of activity had been zero or insignificant.

Similar negative results were obtained in a case where activity was blown into a laboratory by a minor explosion inside a hood. These negative results are very reassuring in such cases.

Whenever appreciable activity is detected by the direct-evaporation method and analytical methods for specific known or suspected contaminants are available, quantitative urinalysis should, of course, be made after the initial large elimination has subsided.

Removal of Potassium

Since the presence of potassium drastically limits the sensitivity of the evaporation method of urinalysis, it was natural to seek a method for removing it. Removal must be done in such a way as to remove a minimum of other substances and not add to the weight of the dry residue to be counted.

Practically complete removal of potassium has been achieved by precipitation with sodium cobaltinitrite. Although this method has lost favor for quantitative determination of potassium, it is very useful for the removal of this substance from solution.

The urine is first acidified using 1 cm³ of 1*N* nitric acid per 100 cm³ of urine. Cobaltinitrite solution (1 gm/5 cm³ water) is then added to the urine and allowed to stand for 2 hours before filtering; 2 cm³ of the solution is sufficient to remove all potassium from a 100-cm³ sample, even of high potassium content. Even in a sample of low potassium content, the unreacted sodium cobaltinitrite does not add objectionably to the solids already present in a 100-cm³ sample.

This reaction is quite specific for potassium. The only other substances removed are lithium, thallium, and ammonium salts.

Removal of Urea

If the potassium is removed from a urine sample, the solids present become the chief factor limiting the sensitivity for detecting radioactive contaminants, since they limit the volume that can be processed and counted. Some improvement in this aspect may be achieved by removing the urea, which constitutes about 40% of the solids present. It can be removed by the action of nitrous acid, according to the following procedure.

1. Acidify the urine sample with 5 cm³ of sulfuric acid per 100 cm³ of urine.

2. Prepare barium nitrite solution (15 gm/100 cm³) and add to the acidified urine by means of a dropping funnel. If the rate of addition is properly adjusted and the sample is stirred, objectionable frothing can be held to a minimum.

3. Remove the resulting barium sulfate precipitate by filtration or centrifugation.

Isotopes of barium, strontium, and possibly lead will be coprecipitated with the barium sulfate, a fact that somewhat limits the usefulness of this procedure.

Discussion

The sensitivity of the direct evaporation method can be increased by about a factor of 10 by removing the potassium. Since this can be done rather simply without greatly increasing the solids left after evaporation, it is recommended as a standard procedure when making analyses of this type.

Removal of the urea, as a means of reducing the solids, makes possible an increase in the size of the sample processed. It is certainly a far less profitable refinement than the elimination of potassium since no more than a twofold increase in sensitivity results. However, it may be worth while in some cases.

Since the details of urinary elimination by humans immediately after acute exposure are not in general known, an accurate evaluation of the body burden will usually be impossible by the method described even when the exact nature of the contaminant is known. However, by considering the elimination data available for some of the more toxic substances, one can usually establish a range of activity in the first day's elimination that can be considered as unimportant.

For higher levels, after substances with relatively short effective half-lives have disappeared and elimination is from a fairly steady internal distribution of the contaminant, a sensitive quantitative urinalysis may be made and the best possible interpretation of the results carried out.

* * *

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BIBLIOGRAPHY

1. G. A. Sawyer, M. L. Wiedenbeck, *Phys. Rev.* **79,** 490 (1950)
2. David E. Alburger, *Phys. Rev.* **78,** 629 (1950)
3. F. P. Cowan, L. B. Farabee, R. A. Love, *Am. J. Roentgenol. Radium Therapy* (in press); or see AECU-1169.

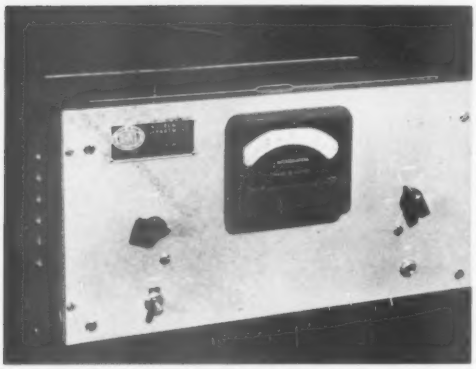

FIG. 1. The a-c powered low-drift electrometer

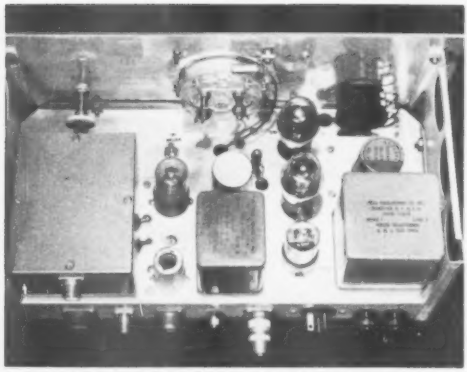

FIG. 2. Rear view of the electrometer chassis

A Simple Low-Drift Electrometer

Very small currents can be measured with a vacuum-tube voltmeter that uses an electrometer tube. Described here is an a-c model that is compact, moderately sensitive, rugged, and inexpensive

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RESEARCH AND INDUSTRY are continually finding new uses for small-current measuring devices. In many instances these measurements must be recorded. For this reason the mechanical electrometers, such as the Lindemann and Hoffman, which at one time were standard equipment in many research laboratories, are rapidly being replaced by electronic instruments.

Of the electronic variety, the vibrating reed* is by far the most popular. The reed has a very fast response time, good stability, and a sensitivity that permits accurate measurements of currents of the order of 10^{-16} amperes. However, it is probable that most small-current measurements do not require either the fast response time or sensitivity of the vibrating reed and therefore do not justify the use of such an expensive instrument. One such application is the continuous recording of ionization current as a function of radiation level.

To answer the need for such measurements, the Oak Ridge National Laboratory Q-826-B Electrometer was designed. The Q-826-B is a compact a-c powered instrument that costs less than $350.00, even when made in small quantities. It is direct reading and drives a 10-mv strip-chart recorder over long periods of time without requiring frequent adjustments of the zero. Its simplicity of design and operation is indicated by the presence on the panel of only three controls, including the on-off switch (Fig. 1). A rear view is shown in Fig. 2.

Stability

The most difficult problem involved in the design of vacuum-tube electrometers is to obtain adequate stability.

Figure 3 shows the circuit of a simple single-tube electrometer. There are five major reasons why a circuit of this type may be unstable. The first and most difficult problem is drift within the tube. Some of these tubes will drift for hours after they have been turned on.

The next troublesome problem is drift resulting from a change in battery voltage. Most batteries have a slight negative voltage drift after a load is applied, even though the load is light. Many show slight changes in voltage as a result of temperature changes. Drift resulting from a voltage change in the plate supply has been minimized in this circuit by making the grid bias proportional to the plate voltage. This is accomplished by using the drop across a resistor in series with both legs of the bridge as the bias voltage (see R_s in Fig. 3).

The third possible cause of drift is a peculiar, and as yet unexplained, phenomenon in electrometer tubes. If the plate voltage is applied before the cathode heats up, the tube has a

*H. Palevsky, R. K. Swank, R. Grenchik, *Rev. Sci. Instr.* **18**, 298 (1947).

Performance of the Electrometer

Full-scale voltage sensitivity	0.25 volts
Full-scale current sensitivity	2.5×10^{-13} amperes
Minimum current that can be accurately measured (instrument used as null indicator)	10^{-15} amperes
Linearity	± 1% of full scale
Drift (after 3 min warmup)	3% of full scale for first hour
	½% per hr thereafter

tendency to drift for hours. This is easily avoided by delaying the plate voltage for a second or two after the filament voltage has been applied. Note the switch arrangement in Fig. 3.

The fourth contributing factor to instability is the change in resistor values as a result of temperature change. Fortunately there are many composition resistors on the market that are good in this respect.

The fifth possible cause of instability is the photosensitivity of the electrometer tube. To eliminate this, the tube must be shielded from light.

A-C Model

In the model Q-826-B, compensation for drift within the tube has been accomplished by the placement of a second electrometer tube in the opposite leg of the bridge (see Fig. 4).

The 5803, a sub-miniature tube manufactured by Victoreen, was chosen on the basis of availability at the time, high leakage resistance (10^{14} ohms), low microphonics, and low grid current. Since the filament current is only 10 ma, the regulated plate supply could be used for filament power.

The triode was preferred to tetrodes and pentodes so that another critical voltage adjustment on the assembly line could be eliminated. Also, wide variations in tube characteristics as a result of changes in current distribution between the screen and plate make tetrodes and pentodes undesirable where long-time stability is required.

The addition of the second electrometer tube to the circuit does not necessarily mean good drift compensation since the wide variation in electrometer-tube characteristics makes it highly improbable that the desired results can be obtained by merely picking two tubes at random.

The tubes should be aged for a minimum of 72 hr and then carefully matched as to plate current for a given grid and plate voltage. The tube ager should be so designed that all plates and grids are in parallel with 6 volts on the plates and 1½ volts on the grid. If the tubes are aged in this manner and then carefully matched, the matched pair will drift in the same direction at approximately the same rate, thus providing good drift compensation. The more closely any two tubes are matched, the better will be their drift characteristics. The tube ager used at ORNL is shown in Fig. 5.

Since less than 15 ma is required to supply both filaments and plates, it was quite easy to obtain sufficient regulation by cascading a VR-150 with

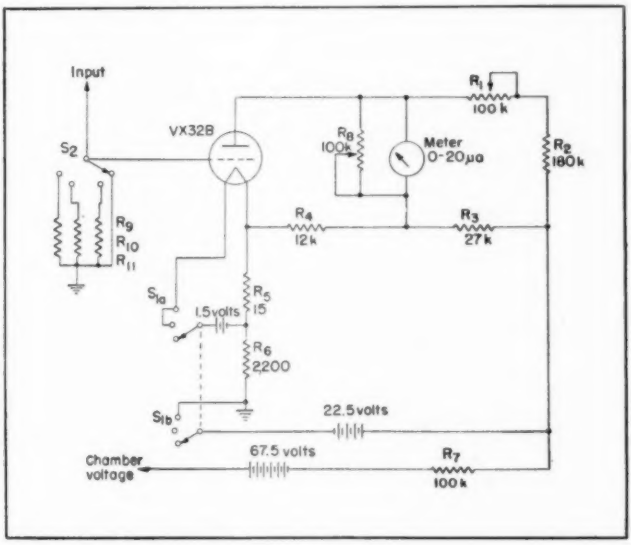

FIG. 3. Circuit of a simple single-tube electrometer

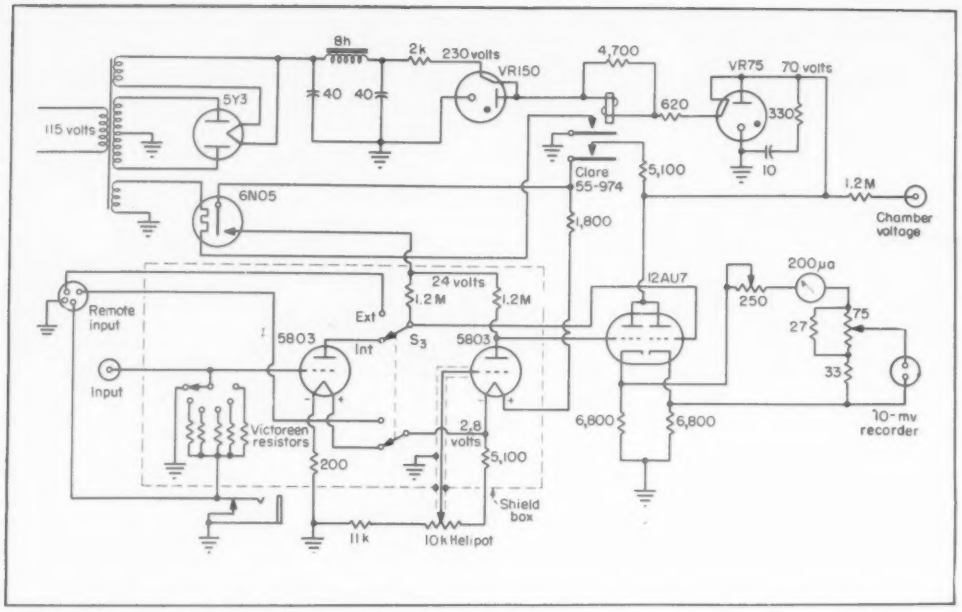

FIG. 4. Circuit of the model Q-826-B a-c powered low-drift electrometer

a VR-75. The degree of regulation required for the two circuits is obviously less than that required for a single-tube circuit. However, additional compensation was added by making the bias voltage a function of both filament and plate voltages. As a result of these two features, a 20% change in line voltage gives no change in meter reading.

Filament safeguards. In any a-c powered electrometer, provisions must be made for safeguarding the filaments. This protection is provided by a relay whose coil is in series with the second VR tube. This relay is not energized until the tube conducts. Since both the plate and filament circuits are open until the relay is energized, the tubes are protected against over-voltage before the VR tube strikes. Energizing the relay provides filament voltage immediately but does not energize the plate circuit. A second set of normally open contacts on the relay energizes a thermal-delay relay which closes the plate circuit after a few seconds delay. This prevents the drift that results when the cathode does not reach operating temperature before the plate voltage is applied.

Use as a voltage amplifier. Although the 5803 is used as an impedance-matching device with an enormous current gain, there are several advantages to be gained by using it as a voltage amplifier, directly coupled to a cathode follower. The addition of the cathode follower makes possible the use of a much larger and more reliable meter than the small 20-ma meters that are commonly used in the plate circuits of electrometer tubes. By dividing the current gain between the electrometer tube and the cathode follower, optimum operating conditions for low grid current, good linearity and long tube life can be realized.

The curves in Fig. 6 show the low grid current and the degree of linearity obtained when the 5803 tube is operated at reduced heater current with a 1.2-megohm plate load. At this plate load, the filament current is 9.5 ma. Since I_g is a linear function of E_g over the entire operating range, the departure from linearity as a result of grid current is zero. It is also apparent that the displacement from zero as a result of grid current when using a 10^{12}-ohm grid resistor is less than ½% of full scale. Grid resistors larger in value than 10^{12} ohms should not be used.

The average cathode current in this application is only 12 μa. At this value no bad effects result from reducing the filament current to 9.5 ma. The average tube life to be expected under these conditions is from 15,000 to 20,000 hr. If good stability is essential, the same care should be exercised in aging and selecting the 12AU7 tube as was used in selecting a balanced pair of 5803 tubes.

Remote ion chambers. The versatility of the instrument is increased by the inclusion of a ganged switch, S_3. In cases where the source of current is remote from the instrument, S_3 is used to switch the input circuit from the first electrometer tube to an additional 5803 tube mounted directly at the source of current. Ion chambers can then be removed to distances of the order of 100 ft without increasing the response time of the instrument. The closed circuit jack in the grid return enables one to plug in a potentiometer and use the instrument as a null-balance electrometer.

Insulators used. The insulators used play an important part in determining the sensitivity and stability.

Parallel leakage paths have been cut to a minimum. It will be noted in Fig. 2 that the cable connector on the shielded compartment at the right end of the chassis is directly opposite the selector switch. This permits the electrometer grid to be tied directly to a bus bar between the switch and the connector, thus limiting the parallel leakage paths to three. All insulators in the input circuit are of the highest quality commercially available. The cable connector is an IPC-9700 with Teflon insulation. The leakage resistance of this connector is better than 10^{15} ohms, and is not affected by humidity. The selector switch is one of Centralab's ceramic series that has been impregnated with polystyrene.* The average input leakage resistance including the tube is approximately 1.5×10^{14} ohms.

Response time. The only step taken in the design of this instrument to reduce the response time was to minimize stray capacity in the grid circuit. The RC time constant of the input circuit is approximately 10 sec when the 10^{12}-ohm range is used. Every additional micromicrofarad of capacity added by the ion chamber means an additional second in the time constant. Therefore, the chamber should be mounted directly on the electrometer to eliminate cable capacity. If this is not possible, an input tube can be located at the chamber and connected by cable to the instrument. This method is recommended for any grid resistors above 10^{10} ohms if the chamber is to be remotely located.

Use as a null indicator. When the instrument is used without the recorder, a higher degree of accuracy and increased sensitivity can be obtained by substituting a sensitive galvanometer in place of the 200-μa meter. Thus, by placing a potentiometer in series with the grid resistor on the grounded side, the instrument can be used as a null indicator to read the IR drop across the grid resistor. Currents of the order of 10^{-15} ampere can be easily and accurately read.

Some of the instruments in use at ORNL have been recording activities continuously for eight months without being serviced. Some of them have gone for weeks with less than 1% drift in zero. In fact they have earned the nickname "the poor man's reed." —END

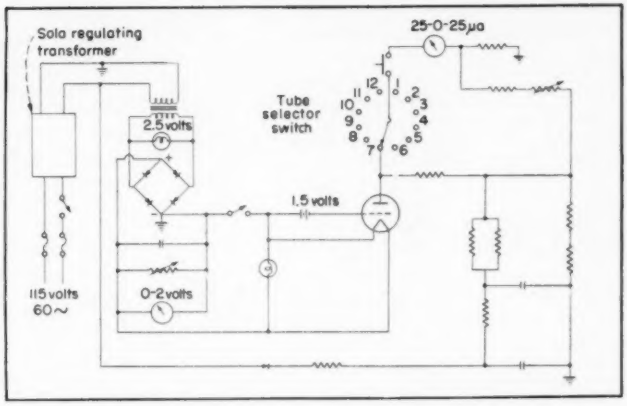

FIG. 5. Circuit of the tube ager that is used at Oak Ridge National Laboratory

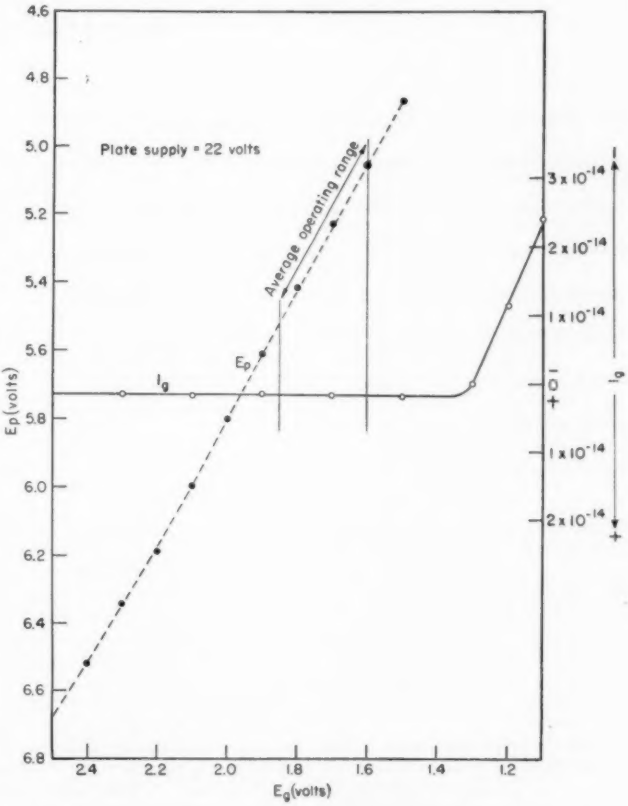

FIG. 6. Voltage and current characteristics of the type 5803 electrometer tube

*F. M. Glass, *Rev. Sci. Instr.* **20**, 239 (1949).

TABLE 1—Rate of Excretion of C^{14} Following Injection of $NaHC^{14}O_3$ into Mice (18 μc)

Period	Specific activity of exhaled $C^{14}O_2$ (μc/mole C)	% of total injected activity	Cumulative % of total activity
0–10 min	13,770	66	66
10–20 "	3,603	16	82
20–30 "	1,750	6.2	88.2
30–60 "	500	4.6	92.8
1–2 hr	84	1.3	94.1
2–4 "	24.1	0.65	94.75
4–6 "	11.2	0.26	95.01
6–12 "	5.6	0.44	95.45
12–24 "	4.8	0.59	96.09
24-hr composite urine sample	115.1	1.35	97.39

TABLE 2—Specific Activities of Tissues at Periods After Injection of $NaHC^{14}O_3$ (18 μc)

Period after injection	Blood	Liver	Brain	Jejunum	Long bone	Long bone shaft
24 hr	1.1	1.1	0.26	2.16	1.89	1.08
1 wk	0.25	0.48	0.18	0.18	0.33	....
1 mo	0.11	0.02	0.13	0.02	0.11	0.25
3 mo	0.10	0.07	0.03	<0.009	0.09	0.15
5.3 mo	....	<0.009	0.01	<0.009	0.04	0.06
8.7 mo	....	<0.009	<0.009	<0.009	0.07	0.12
10.2 mo	....	.....	.....	.....	0.04	0.05
10.7 mo	....	.....	.....	.....	0.06	0.10
12.7 mo	....	.....	.....	.....	0.03	0.04

The Hazard Involved in

The most popular of the radioisotopes, carbon-14 is employed in hundreds of laboratories. When used with caution and as an experimental tool, it is considered nonhazardous. Evidence and new data to support this conclusion are reviewed here, together with a discussion on the nature of the hazard

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WHEN CARBON-14 first became available from the Atomic Energy Commission, it was considered one of the more dangerous isotopes because of its long half-life (about 5,500 years) and because of the well-known entrance of carbon from carbon dioxide into the organic and inorganic metabolic pathways. This picture has gradually changed.

When employed at usual experimental levels with reasonable precautions, C^{14} is now generally assumed to be nonhazardous. In support of this assumption, this paper presents certain basic experimental evidence that seems to bear on the question of the hazard involved in laboratory use of C^{14}.

The two C^{14}-containing substances with which the laboratory worker comes into contact most frequently (prior to dilutions with inactive carbon) are C^{14}-carbon dioxide and C^{14}-barium carbonate. Obviously, the former can be inhaled as such, and barium carbonate can, when dry, be inhaled as a dust or aerosol. It is also apparent that in many C^{14}-labeled organic compounds the biological fate of the isotope is oxidation to $C^{14}O_2$.

To assess the most obvious hazards involved in the use of C^{14}, one must know the:

1. Degree of exchange of inspired $C^{14}O_2$ with blood bicarbonate at sites of blood aeration in the lungs.
2. Retention of bicarbonate carbon in the blood and various tissues (this depends on the exchange and on the rates of metabolism, i.e., CO_2 fixation and turnover).
3. Degree of localization of the isotope within certain more-or-less-active cells within various tissues.
4. Stability of $BaC^{14}O_3$ particulates retained by the lung on inspiration of $BaC^{14}O_3$ aerosol.
5. Inherent carcinogenicity of C^{14} due to the physical characteristics of its atomic disintegration.

Carbon Dioxide and Bicarbonate

Brues and Buchanan (*1*) have provided information on the retention of C^{14} by fixation of inhaled $C^{14}O_2$ gas. They observed that the lungs absorb $C^{14}O_2$ very efficiently in spite of the mass movement of CO_2 in the opposite direction. It appears that the amount of $C^{14}O_2$ absorbed to reach equilibrium with the blood bicarbonate depends on the specific activity of the alveolar atmosphere and thus is largely independent of the CO_2 concentration in

TABLE 3—Per Cent of the Total Injected C^{14} Retained at Various Periods

At end of	*Total body*	*Skeleton*	*% of retained activity in skeleton*
24 hr	1.4	0.25	18
48 hr	0.94	0.19	20
1 wk	0.62	0.09	15
2 wk	0.20	0.07	35
1 mo	0.13	0.03	23
3 mo	0.12	0.03	25
5.3 mo	<0.02	0.01	>50
8.7 mo	<0.04	0.03	>75
10.3 mo	.....	0.02	....
12.7 mo	.....	0.01	....

TABLE 4—Total Body and Skeleton Radiation Calculations on $NaHC^{14}O_3$ Injected Mice

Period	*Body radiation in average daily r per period*	*Skeleton radiation in average daily r per period*
0–24 hr	0.11	0.07
1–2 days	0.027	0.033
2–7 days	0.022	0.021
1–2 wk	0.009	0.016
2–4 wk	0.004	0.008
1–3 mo	0.003	0.004
5.8–6.2 mo	.....	0.004
8.7–10.2 mo	.....	0.004
10.8–12.2 mo	.....	0.002

NOTE: Maximum tolerated level estimated at 0.05 r per day

the Use of Carbon-14

the inhaled air. Brues and Buchanan state that "in general, following exposure, C^{14} is removed at a rate comparable to that of its uptake, and the same is probably true of its incorporation into compounds in a steady state. One probable exception exists in the case of growing tissue and, of course, where exposure is continuous over a long period."

It has been adequately demonstrated that the major fraction of the C^{14} from labeled bicarbonate injected into animals is expired within a short time (about 65% in 10 min; >90% in 4 hr) (*2, 3, 4*). Table 1 gives certain data we have obtained on this subject (*4*).

This rapid initial turnover of the greater portions of the C^{14} in blood bicarbonate is consoling. However, it seems important to know something of the degree and duration of tissue exposure to C^{14} following the intake of compounds labeled with this isotope, especially bicarbonate. The degree and duration of exposure of tissues to the β-particles from C^{14} are dependent on concentration and turnover, both of which are in turn dependent on the carbon-utilizing metabolic system involved and its dynamic state. Tissue exposure data can best be obtained by following the quantitative gross distribution and turnover of C^{14} in animals for extended periods.

Bloom, Curtis, and McLean (*5*) showed by autoradiographic technique that the bones of rats injected with $BaC^{14}O_3$ (75 to 100 μc) retained activity at 16 weeks. Sections of liver and kidney gave fairly intense autoradiographs at 3 days and 2 weeks, but were negative after longer intervals.

Armstrong, Schubert, and Lindenbaum (*2*) in studies of the distribution of radiocarbon administered as carbonate observed retention in soft tissues, bones, and teeth at 6 days and in certain cellular constituents at 40 days.

We have carried out certain experiments designed to obtain quantitative data on $C^{14}O_2$ fixation, from which tissue, organ, and total body exposure can be estimated (*4, 6*). To be able to carry on these experiments over long periods, and to avoid use of excessive amounts of C^{14}, it was necessary to employ extremely sensitive counting techniques (*7*) and small animals.

Using the principles described by Miller (*8*), Dr. Locke White, Jr., of our Physics and Physical Chemistry Division, constructed a gas-phase apparatus, which has allowed us to determine rather accurately the C^{14} content of mouse bones one year after injection of 18 μc of $NaHC^{14}O_3$. Because of the excellent geometry of this Geiger tube (*7*), almost all disintegrations are recorded, allowing for estimates of absolute activity of $C^{14}O_2$ from oxidized tissue samples.

Adult mice were injected intraperitoneally with 18 μc of $NaHC^{14}O_3$ (2.5 mg of sodium bicarbonate with a specific activity of 600 mc/mole of carbon). This is approximately a 50-mc man-equivalent. The specific activities of a number of samples of tissues, blood, and bone were then determined at 24 and 48 hours, 1 and 2 weeks, and 1, 3, 4, 5, and 9 months (*4, 6*). From these specific activities and knowledge of the tissue weights, estimates of the total activity in each tissue sample were made.

After 3 months, none of the soft tissue retained significant quantities, so that later assays were limited to bone. Bone activities have now been followed as long as 12.7 months (*7*). Certain of the data on this subject have been selected for illustrative purposes in Table 2.

Calculations on the per cent of the total injected C^{14} from $NaHC^{14}O_3$ retained in the body and the skeleton at various periods are presented in Table 3.

Knowing the approximate amount of C^{14} in the body or a portion thereof

Bone Section: 24 Hours

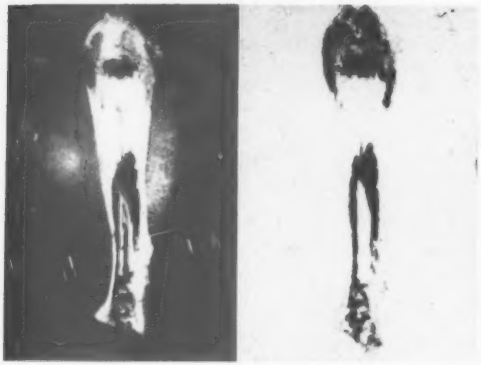

FIG. 1. Bone section and autoradiograph from a mouse at 24 hours after injection of 18 μc of C^{14}-bicarbonate ("No-Screen" X-ray film exposed for 30 days prior to development)

Bone Section: 6 Months

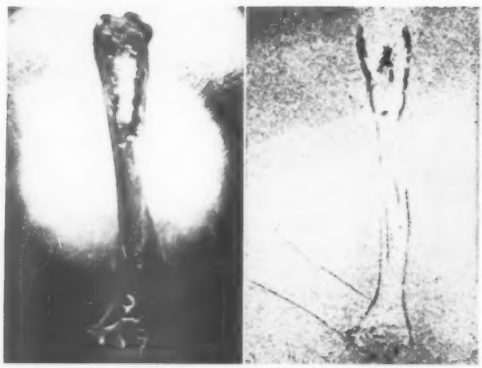

FIG. 2. Bone section and autoradiograph from a mouse at 6 months after injection of 18 μc of C^{14}-bicarbonate (X-ray film exposed for 5 months)

and the average energy of radiation of this isotope, it is possible to convert tissue or total-body activities (integrated) into roentgen units.

Assuming equal distribution in the body and in the skeleton, radiation calculations have been made and are presented in Table 4. The latest estimates on the maximum permissible dose for any tissue is 0.3 r/wk (*9*), or 0.05 r/day.

Since it is well known that C^{14} emits a very soft β-ray that traverses only several cell diameters, such data as have been presented in Table 4 do not present a picture of the maximum radiation in limited areas of slow turnover. It has been considered worth while to attempt to estimate the degree of radiation possible in areas of the bone where, as indicated by autoradiographs, C^{14} retention is highest.

Autoradiographs were prepared by embedding bones of $NaHC^{14}O_3$-injected mice in plastic, and then grinding about half way through the bone. These sagittal sections were then placed in close contact with "No-Screen" X-ray film for about 4 or 5 months (*6*). Figures 1 and 2 show typical autoradiographs made from bones taken at various periods after injection of 18 μc of C^{14} bicarbonate.

As can be seen from the righthand picture in Fig. 2, the "active" area (after 2 weeks) can be considered roughly as a cylinder with a wall thickness the average width of the parallel black lines. Hence the active volume can be approximated from actual measurements by multiplying the average length of the lines by the average width and multiplying that by πD, where D is the diameter of the hypothetical radioactive cylinder containing the preponderance of C^{14}.

Such measurements have been made with a calibrated filar micrometer on bone autoradiographs from mice sacrificed 2 weeks, and 5.8, 6.2, and 6.3 months after injection with C^{14}-bicarbonate (18 μc). Based on total activity determination on corresponding bones in the same mouse, calculations have been made on total activity per cubic millimeter of "active" bone and the approximate degree of radiation (r/day) received by the "active" bone. These values are summarized in Table 5.

Such calculations are, of course, approximate, and it is fully appreciated that the assumption that all of the active carbon in the bone is contained in the so-called active volume is not a valid one. It, however, is a conservative one, and the calculations given in Table 5 provide radiation values which are believed to be of the correct order.

These calculations imply that for the period of 1 to 2 weeks after injection of

TABLE 5—Radiation Received per Day by "Active" Volume of Bone at Periods After Injection of $NaHC^{14}O_3$ (18 μc)

Period	*Volume of active bone* (mm^3)	*Activity per unit "active" volume* ($m\mu c/mm^3$)	*Average radiation in active bone* (*r/day*)
1–2 wk	8.2	0.04	0.16
5.3–5.8 mo	3.7	0.03	0.04
5.8–6.2 mo	5.4	0.02	0.04
6.2–6.3 mo	6.6	0.01	0.03

TABLE 6—Particle Size Distribution of a $BaC^{14}O_3$ Aerosol Measured by Microscopic Inspection

Diameter (microns)	*% of particles*
<2	70.5
2–3	20.8
3–4	6.3
4–5	1.9
>5	0.5
	100.0

TABLE 7—Specific Activities of Lungs after Exposure to an Aerosol of $BaC^{14}O_3$

Expt. No.	Specific activity of $BaC^{14}O_3$	Period of exposure (min)	Time of sacrifice	Specific activities (μc/mole C)			
				Lungs	Spleen	Kidneys	Liver
1	6,700	66	Immediate	0.03			
			24 hr	<0.005			
			48 hr	<0.005			
			7 days	<0.005			
2	20,000	120	Immediate	0.02			
			1 hr	0.03			
			3 hr	<0.005			
3	200,000	30	Immediate	0.04	<0.005	0.01	<0.005
			Immediate	0.05			
			24 hr	0.016			
			24 hr	<0.005			

NOTE: All activities are on individual mice sacrificed at indicated intervals.

TABLE 8—Specific Activities of Exhaled CO_2 from Mice Exposed to a $BaC^{14}O_3$ Aerosol

Period (days)	Specific activity of exhaled CO_2 (μc/mole C)
0–1	0.31
1–2	0.06
2–5	0.11
5–6	0.09
6–7	<0.01

TABLE 9—Effects of Injection of $NaHC^{14}O_3$ (18 μc) on the Pattern of Death from Spontaneous Leukemia

	Controls	$NaHC^{14}O_3$
Mortality	13/13	15/15
Average age at leukemic death	306 days	308 days
Standard deviation from mean	51.2 days	79.0 days

18 μc of C^{14}-bicarbonate into mice, certain bone shaft cells were receiving about 0.16 r/day, but that after 4 months this "active" area bone was receiving about 0.04 r/day. Since the recommended maximum permissible dose for any tissue is 0.05 r/day, it would appear that an 18-μc dose for a 25-gm mouse (a 50-mc man-equivalent) produces localized radiation which is, for a time, above the allowable level.

Barium Carbonate

The possible hazard from C^{14}-barium carbonate dust inhaled by the laboratory worker has been a source of considerable concern.

Govaerts (*10*) has studied the rate of elimination of C^{14} administered as $BaC^{14}O_3$ by intraperitoneal injections in rats. He reported that "in preliminary experiments, 30–60 minutes after injecting the barium carbonate, C^{14} was rapidly fixed by the lungs and no significant activity was found in soft tissues." The excretion of the C^{14} by the lungs was very rapid, about 45% of the total injected C^{14} being expired during the first hour and about 85% in 12 hours. Approximately 88–99% of the total activity was expired and excreted (apparently in about 2 days).

This author cannot understand why Govaerts was unable to demonstrate significant $C^{14}O_2$ fixation in all tissues after $BaC^{14}O_3$ injections since, in his experiments, there was obvious whole-sale exchange with body carbonate.

Using a procedure suggested by Dr. H. D. Landahl of the University of Chicago Toxicity Laboratory, we have been able to set up a $BaC^{14}O_3$ aerosol of primary particles for animal exposures. A small amount of $BaC^{14}O_3$ was placed in a 250-ml three-necked reaction flask with an appropriate inlet and outlet. The inlet tube was drawn down to about a ½ liter/min orifice (under 15 psi) and inserted through a rubber stopper so that the lower end was about 1 in. from the bottom of the flask. Air pressure was then applied (15 psi) to the affluent of the system while gently but rapidly tapping on the flask with a rubber-covered striker from an electric bell. The larger particles were removed in additional flasks.

A $BaC^{14}O_3$ aerosol, so produced, appeared to be very fine and could be detected by means of a Tyndall beam an hour after it was set up in a glass desiccator used as an animal chamber. Its particle-size distribution was estimated by microscopic inspection (using a filar micrometer) of settled particulates; see Table 6.

Mice have been exposed to $BaC^{14}O_3$ aerosols of different specific activities and sacrificed for tissue C^{14}-assays at various intervals. The results (*11*) are presented in Table 7.

In addition, mice were exposed to a $BaC^{14}O_3$ aerosol, removed from the exposure chamber, and placed in a metabolism chamber where exhaled CO_2 was collected for one week. The specific activities of the exhaled $C^{14}O_2$ are given in Table 8.

These findings seem to confirm those on injected $BaC^{14}O_3$ which suggest that an inhaled particle of barium carbonate exchanges its carbon atoms fairly rapidly with body pool carbonate and that inhaled $BaC^{14}O_3$ is perhaps not as dangerous as might have been expected on the basis of its insolubility.

Effects of C^{14} on Mice with Spontaneous Leukemia

It seems important, along with studies on the absorption, retention, distribution, and turnover of C^{14} when administered in various chemical states, to make some direct observations on the carcinogenic activity of this radioisotope.

Preliminary investigations have been reported (*12*) on the failure of a single dose of $NaHC^{14}O_3$ (18 μc, a 50-mc-man equivalent) to affect the pattern of deaths of Akm mice from spontaneous leukemia. This strain of animal, because of inbreeding, develops spontaneous leukemia in almost 100% of cases at about 9–10 months of age. When young Akm mice were injected with $NaHC^{14}O_3$ and set aside to await development and death from spontaneous leukemia, it was observed that their pattern of deaths was no different from litter-mate controls injected with nonradioactive bicarbonate;

the results of this study are summarized in Table 9.

Similar studies have now been carried out with low levels (1.4 μc) of C^{14}-labeled 2,6-diaminopurine, which acts as a precursor of chromosome guanine, and with high levels of C^{14}-formate (250 μc, a 700-mc man-equivalent), which acts as a precursor of the 2- and 8-carbon atoms of desoxyribose nucleic and ribose nucleic acid purines and the methyl carbon atom of thymine. The effects of these C^{14}-labeled compounds on the pattern of deaths from spontaneous leukemia in mice was likewise insignificant (*11*).

One of the more sensitive methods of detecting radiation effects in animals is by means of white blood counts. Leukemic white-blood-cell production is apparently more sensitive to radiation than normal hematopoiesis. We have injected leukemic mice with 100 μc of $HC^{14}OONa$ and observed no depression of the high white blood count (*13*). Also it was observed that 200 μc of $HC^{14}OONa$ (a 500-mc man-equivalent) had no effect on the life span of mice with transplanted Ak-4-leukemia (*13*).

These experiments suggest that C^{14} (even when temporarily incorporated into the chromosome, which is the case with isotopic formate) at the levels indicated has no profound cytotoxic activity.

Conclusions

In summary, we might make the following guarded statements:

1. Inhaled $C^{14}O_2$ exchanges with blood bicarbonate fairly extensively, but by the same token is not retained in the body to any great extent. The blood bicarbonate is turned over largely in a matter of minutes.

2. Of the inhaled $C^{14}O_2$, a small amount is fixed in body tissues. The turnover of this C^{14} is dependent on many metabolic processes. The turnover of C^{14} from bicarbonate in the bone is much slower than that in the soft tissues.

3. After injection of 18 μc of C^{14}-bicarbonate into mice (a 50-mc man-equivalent), the body and the skeleton as a whole receive greater than the maximum permissible level of 0.05 r/day for only about 24 hours. However, certain areas in the bone are receiving greater than this amount for several months.

4. The carbonate moiety of $BaC^{14}O_3$ absorbed in the lungs does not remain as such, but turns over very rapidly by exchange with inactive CO_2 in the moist atmosphere of the lungs.

5. Fairly high levels (a 50-mc man-equivalent of $NaHC^{14}O_3$ or a 700-mc man-equivalent of $HC^{14}OONa$) have shown no effects on the pattern of deaths from spontaneous leukemia in Akm strain mice, nor have indications of cytoxic action been observed on administration of C^{14} at these levels.

* * *

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BIBLIOGRAPHY

1. A. M. Brues, D. L. Buchanan. Studies on the over-all CO_2 metabolism of tissues and total organisms, *Cold Spring Harbor Symposia Quant. Biol.* **13,** 52 (1948)
2. W. D. Armstrong, J. Schubert, A. Linderbaum, *Proc. Soc. Exptl. Biol. Med.* **68,** 233 (1948)
3. R. G. Gould, F. M. Sinex, I. N. Rosenberg, A. K. Solomon, A. B. Hastings, *J. Biol. Chem.* **177,** 295 (1949)
4. H. E. Skipper, Locke White, Jr., C. E. Bryan, *J. Biol. Chem.* **180,** 1187 (1949)
5. W. Bloom, H. H. Curtis, F. G. McLean, *Science* **105,** 45 (1947)
6. H. E. Skipper, C. Nolan, L. Simpson, *J. Biol. Chem.* **189,** 159 (1951)
7. H. E. Skipper, C. E. Bryan, Locke White, Jr, O. S. Hutchison, *J. Biol. Chem.* **173,** 371 (1948)
8. W. W. Miller, *Science* **105,** 123 (1947)
9. Recommendations of International Commission on Radiation Protection, NUCLEONICS **8,** No. 1, 31; No. 2, 70 (1951)
10. J. Govaerts, *Science* **111,** 467 (1950)
11. H. E. Skipper, unpublished data
12. H. E. Skipper, M. J. Bell, J. B. Chapman, *Cancer Research* **10,** 362 (1950)
13. H. E. Skipper, Martelia Bell, J. B. Chapman, *Cancer Research* (in press)

Selection of Materials

For any particular application [in nuclear engineering], it is not sufficient to compare materials purely on the basis of their cross section. Rather it is also necessary to evaluate the materials with respect to the service conditions to which they will be subjected.

As an example, one may wish to encase fissionable material to prevent the escape of fission gases generated during the operation of the reactor. Obviously one must now consider such things as the safe working stress of the material. A convenient way of comparing the various materials is by selecting the property of interest and dividing by the macroscopic cross section. The table at the right lists a number of elements and alloys which are compared using as the property of importance the tensile strength in the hard condition.

Material	*Macroscopic cross section* (cm^{-1})	*Tensile strength* ($lb/in.^2 \times 10^3$)	*Quality factor* $\times 10^3$
Mg	0.016	37	2.3
Al	0.012	24	2.0
Be	0.0011	27	24.0
Fe	0.19	100	0.51
Zr	0.021	88	4.15
Stainless Steel (304)	0.20	87	0.43

It is seen that Be is by far the most desirable material based on these criteria. However, the selection of a material cannot be based on these two criteria alone. One must take into account such other factors as formability, ductility, weldability, availability, cost, and a number of other pertinent properties. For many applications, the lack of ductility and weldability would rule against the use of beryllium with cost as an additional consideration. In theory, one could construct a number of tables similar to this one, using a number of properties as criteria, and then obtain the best material by the cross product of these figures of merit. In actual practice the choice is rapidly narrowed down to one or two materials by certain special requirements.

—David H. Gurinsky, AAAS Meeting Philadelphia, Pa., December, 1951

Determination of Micromicrogram Quantities of Radium

The radium elimination rate from exposed workers can be followed by the method described here. The lower limit of measurement is about 0.1 μμg of radium; above 1 μμg, the accuracy is 20%

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THE WORK OF Martland (*1*) and Evans (*2*) in the field of radium toxicology has shown that the retention of small amounts of radium in the body may cause physical damage. At present, one-tenth of a microgram is considered to be the permissible level for radium permanently fixed in the body. This body radium is usually assessed by a measurement of the radon in the expired breath. However, in monitoring workers who are currently being exposed, it is desirable to follow not only the body radium but its elimination rate as well.

It has been estimated that about 0.01% of the body radium (or about 10^{-11} gm at tolerance) is excreted daily in urine six months after exposure (*3*), and that about 0.0005% (or about 5×10^{-13} gm at tolerance) is eliminated daily by long-standing chronic radium poisoning cases (*4*). The quantities involved when the subjects contain less than the permissible level are correspondingly smaller.

This means that the method of assay should extend to 10^{-13} gm of radium per 24-hr sample. While this is readily accomplished by the emanation method (*5*), the apparatus is expensive and must be custom-made.

Tompkins *et al.* (*6*) have developed a method in which the final radium product is determined by measuring its beta activity under controlled conditions. However, the method is not suited to routine analysis of samples containing less than a micromicrogram.

A method which would be more sensitive is the direct alpha counting of the final radium at full equilibrium with its three alpha-emitting daughters. Ames *et al.* (*7*) developed a procedure for alpha counting of process solutions. This method was further developed by Russell and co-workers for the analysis of radium in urine (*8*) and excreta (*9*).

The method described here, while requiring a long elapsed time of analysis, is economical of operator time. Any low-background alpha counter may be used. The automatic sample-changing scintillation counter developed by the Instruments Branch of this Division is used for routine analyses in our laboratory, but is not essential for operation of the method.

Sample Preparation

The method of preparation of urine samples for counting is as follows.

1. Add NH_4OH to 200 ml of urine in a 250-ml centrifuge bottle until

TABLE 1—Self-Absorption by $RaSO_4$-$BaSO_4$ Precipitate

Plate	Alpha disintegration rate (dpm)	Beta disintegration rate (dpm)	Alpha-to-beta ratio
1	647	298	2.07
2	478	291	1.65
3	547	283	1.93
4	625	308	2.03
5	661	319	2.07
6	622	340	1.83
7	581	340	1.71
8	644	330	1.95
9	594	304	1.95
Average	599	313	1.91

TABLE 2—Coprecipitation of $RaSO_4$ with $BaSO_4$ at Several *p*H Values

Sample	Radium (gm)	Barium (mg)	*p*H	Disintegration rate (dpm)
1	6.8×10^{-12}	1	1	7
2	"	1	3	5
3	"	1	5	6
4	"	2	1	6
5	"	2	3	6
6	"	2	5	6
7	"	4	1	7
8	"	4	3	7
9	"	4	5	19
10	6.8×10^{-11}	1	1	51
11	"	1	3	57
12	"	1	5	53
13	"	2	1	60
14	"	2	3	59
15	"	2	5	65
16	"	4	1	73
17	"	4	3	54
18	"	4	5	57
19	6.8×10^{-10}	1	1	647
20	"	1	3	478
21	"	1	5	547
22	"	2	1	625
23	"	2	3	661
24	"	2	5	622
25	"	4	1	581
26	"	4	3	644
27	"	4	5	594

* PRESENT ADDRESS: U. S. Naval Radiological Defense Laboratory, San Francisco, California.

TABLE 3—Statistical Analysis of the Data

Factors	*Degrees of freedom*	*Sum of squares of deviations*	*Mean squares*	*F ratios*
Single factors				
Radium	2	1,938,422	969,211	661.12
Barium	2	3,956	1,078	1.35
*p*H	2	561	281	0.19
Interactions				
Ba × *p*H	4	4,654	1,164	0.79
Ra × *p*H	4	994	248	0.17
Ra × Ba	4	5,681	1,420	0.97
Ra × Ba × *p*H (error)	8	11,733	1,466	

TABLE 4—Recovery of Radium from Water and Urine Samples

Plate	*Radium samples (dpm)*	*Water samples (dpm)*	*Urine samples (dpm)*
1	56	51	51
2	62	47	54
3	66	53	58
4	56	60	66
5		59	67
6		65	69
7		73	55
8		54	71
9		57	67
Average	60	59	61

precipitation is complete (*p*H about 7).

2. Centrifuge, discard supernatant liquid.

3. Wash precipitate with 25 ml of 10% NH_4OH.

4. Centrifuge, discard supernatant liquid.

5. Dissolve the precipitate in a few milliliters of acetic acid and add 200 ml of distilled water.

6. Bring the solution to a *p*H of 5 with NH_4OH (*p*H test paper).

7. Add 3 to 4 gm of $(NH_4)_2SO_4$, 1 ml of 0.015*M* $BaCl_2$ (2 mg Ba^{++}), stir well, digest overnight.

8. Filter through fine filter paper, wash with 0.5% H_2SO_4.

9. Place filter paper with precipitate in a small platinum dish, ignite at 800–900° C.

10. Add 2 ml of 1:1 H_2SO_4, 5 ml of 48% HF, and evaporate on a sand bath until SO_3 fumes appear.

11. Transfer to a 50-ml centrifuge tube with 40 ml of distilled water and digest overnight.

12. Centrifuge and discard supernatant liquid.

13. Wash precipitate with 10 ml of distilled water, centrifuge and discard supernatant liquid.

14. Wash precipitate with 10 ml of 95% ethyl alcohol, centrifuge and discard supernatant liquid.

15. Transfer precipitate with ethyl alcohol onto a round nickel plate 2.8 cm in diameter, and dry under an infrared lamp.

16. Count on a low-background alpha counter for one hour.

Process Variables

There are three major variables in this method of determining micromicrogram traces of radium in urine samples. These variables are

1. The completeness of coprecipitation in the three precipitation steps.

2. The self-absorption by the precipitate of the alpha particles.

3. The degree to which the radon is retained by the precipitate to allow build-up of the equivalent of four alphas per radium disintegration.

The radium solution used was standardized by measuring alpha disintegration rates of aliquot samples. Portions ranging from 0.1 to 0.5 ml were pipetted onto the 2.8-cm nickel plates and dried under an infrared lamp. The samples were allowed to stand 30 days to establish radioactive equilibrium and the alpha disintegration rate was determined. The average value for the radium content of the solution was 6.8×10^{-11} gm of radium per milliliter.

The self-absorption was checked by running 1-ml portions of the standard solution through the final barium sulfate coprecipitation and determining the alpha and beta activity at full equilibrium. The results are shown in Table 1.

Theoretically, in the decay chain, there are alphas from Ra^{226}, Rn^{222}, Po^{218} and Po^{214}, and betas from Pb^{214} and Bi^{214}, before the long-lived product Pb^{210} is reached. Thus, the alpha-to-beta ratio should be two to one. The ratio obtained indicates a slight alpha absorption, ignored in routine work.

Statistics

After exploratory work in the final coprecipitation of traces of radium, the amount of barium and the *p*H were selected as the variables to be studied with a factorial experiment. The samples were counted at full equilibrium. The experimental data are given in Table 2.

The factorial design is useful for determining whether variations due to the factors studied are greater than might be expected from purely random variations. Also, the significance of interactions between pairs of factors may be determined. In the design used, replications were not run to evaluate the random error, but the second-order interaction between the three factors was taken as the error term. A description of the statistical methods may be found in any of the standard texts on experimental statistics. The analysis of the factorial experiment is given in Table 3.

TABLE 5—Recovery of Radium from Urine Samples

Sample	*Radium added (μμg)*	*Radium found (μμg)*	*Recovery (%)*
1	0.068	0.082	120
2	0.34	0.27	80
3	0.68	0.72	105
4		0.65	95
5	3.4	3.3	95
6		3.1	90
7	5.5	6.8	125
8	6.8	6.1	90
9		6.5	95
10	20	20	100
11	44	46	105
12	68	65	95
13		65	95
14	680	710	105
15		750	110
16	1,360	1,410	105
17		1,120	80
		Average	100

The F ratios given in Table 3 are the ratios of the mean square of the factor to the mean square of the error. By comparing the F ratios in Table 3 with those tabulated by Fisher and Yates (*10*) (to locate ratios of less than unity in the tables, the reciprocal value must be used) it is seen that in the range studied, the effects of barium, *p*H, or the interactions are without significance. The amount of radium, as expected, is highly significant.

Four nickel plates containing 0.1 ml of standard radium solution were dried under an infrared lamp and given 40 days to reach full equilibrium. The average number of disintegrations per minute was 60. The average disintegrations per minute from nine 200-ml water samples and nine 200-ml urine samples spiked with the same amount of radium were 59 and 61 respectively (Table 4). From this data, it can be seen that there is very little difference in disintegrations per minute in the original radium solution transferred directly onto the nickel plates and the amount recovered from the spiked water and urine samples.

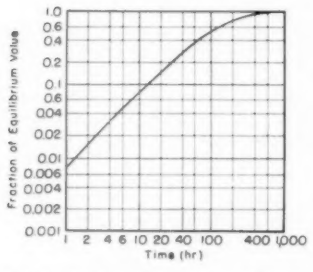

FIG. 1. Build-up of radon from radium

It is not necessary to wait for full equilibrium to be reached since the build-up of alpha activity follows the build-up of radon shown in Fig. 1. The final activity may be calculated from the fraction, F, of the final activity present at any time after the final coprecipitation by

$$\text{Final dpm} = \text{Measured dpm}\left(\frac{4}{1+3F}\right)$$

This expression is valid at any time after a few hours following the final coprecipitation.

The recovery of radium added to urine samples is shown in Table 5.

With the counters used, the limit of practical determination is considered to be 10^{-13} gm of radium, for a 60-min count, on units having a background counting rate less than 0.1 cpm and a geometry of 40%.

The counting statistics involved in low-level counting are outlined in Table 6, which gives the standard deviations for various net counting rates when the background is 0.1 cpm. The standard deviations given are a maximum, as the background is normally less than 0.1 cpm and low-level samples are counted for longer periods.

TABLE 6—Statistics for Low-Level Counting

Net counting rate (cpm)	*Expected standard deviations*	
	30-min count	*60-min count*
0.1	0.085	0.056
0.2	0.10	0.07
0.3	0.12	0.08
0.4	0.13	0.09
0.5	0.14	0.10
1.0	0.19	0.14
2.0	0.27	0.19
5.0	0.36	0.29

Thus, for 10^{-13} gm of radium, having a disintegration rate of 0.88 dpm, we should obtain 0.35 cpm. Fifty per cent of tests on such a sample should be within the limits 0.35 ± 0.06 cpm, and 95% within 0.35 ± 0.17 cpm.

BIBLIOGRAPHY

1. H. S. Martland, P. Conlon, J. P. Knef, *J. Am. Med. Assoc.* **88,** 1769 (1925)
2. R. D. Evans, *J. Ind. Hyg. Toxicol.* **25,** 253 (1943)
3. H. E. Silberstein, AECD-2122 (1945)
4. R. D. Evans, J. C. Aub, D. M. Gallagher, D. M. Tibbets, *Ann. Internal Med.* **11,** 1443 (1938)
5. R. D. Evans, *Rev. Sci. Instr.* **6,** 99 (1931); **13,** 147 (1942)
6. P. C. Tompkins, W. P. Norris, L. Wish, R. D. Finkle, MDDC-699 (1946)
7. D. P. Ames, J. Sedlet, A. H. Anderson, T. P. Kohman, AECD-2696 (1949)
8. E. R. Russell, R. C. Lesko, J. Schubert, NUCLEONICS **7,** No. 1, 60 (1950)
9. E. R. Russell, MDDC-226 (1946)
10. R. A. Fisher, F. Yates, "Statistical Tables" (Oliver and Boyd, London 1938)

The Argument for Standardization

The "tailor-made" laboratory [for handling radioactive materials] must be eliminated in favor of a standardized design if an economical design and early completion of construction are desired.

Attempts to attain "tailor-made" laboratories will result in the following:

1. Frustration of design personnel in their efforts to design efficient and economical facilities with incidental impairment in their efficiency in preparing drawings and specifications.

2. Ultimate delay in completion of construction resulting from indecision with respect to requirements as well as additional design time required to develop "tailor-made" requirements into construction documents.

3. Increased difficulty in establishing and maintaining adequate operating techniques and procedures because of the complexities of multiple non-standard systems with incidental ultimate deterioration of operating capabilities.

4. Sacrifice of the very desirable procedure of maintaining a stock of standard replacement parts which becomes impracticable with the "tailor-made" systems because of the multiplicity of parts required.

5. Seriously increased initial construction as well as maintenance and operating cost resulting from the special systems provided.

—*C. P. Roberts, AIA-AEC meeting on Laboratory Design for Handling Radioactive Materials, November, 1951*

"Air Equivalence" of Scintillation Materials

For scintillation counters to yield information in roentgens, the scintillator must be "air equivalent." The air equivalence of common scintillators is discussed here from the standpoint of energy absorption and crystal response. Methods of simulating air equivalence are presented

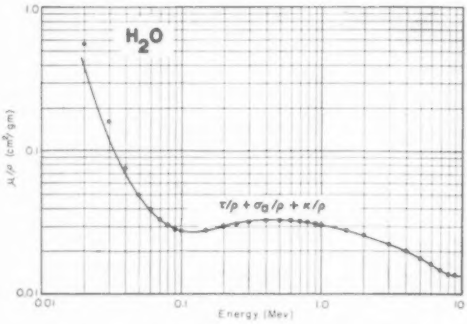

FIG. 1. Sum of the various mass absorption coefficients of H_2O as a function of the quantum energy. Plotted points represent values given by Marinelli *et al.* (8)

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APPLICATION of scintillation methods to the measurement of dosage in radiation therapy requires availability of "air-equivalent" scintillation media. It is well known that bombardment of certain organic crystals with monoenergetic electrons produces scintillations which may be observed on an oscilloscope screen as pulses of given amplitude. The relationship between electron energy and pulse height is, for all practical purposes, linear. This relationship has been verified by a number of investigators (*1*), and is the basic principle of the scintillation spectrometer (*2, 3*).

To obtain a crystal which responds in a manner equivalent to air, the absorption of the primary radiation in the thickness of the crystal must be proportional to the absorption of the primary radiation in an equivalent thickness of air.* Because the majority of dosage measurements in the field of radiation therapy involve primary X- or gamma radiation, it is this problem with which we will be concerned.

Energy may be absorbed from a photon beam at energies below 10 Mev by three different processes—photoelectric absorption, Compton absorption, and pair production. To calculate the total absorption coefficient μ involving energy transfer to the absorbing medium, it is necessary to calculate the sum of the fractional mass-absorption coefficients due to the various reaction mechanisms, i. e.

$$\tau/\rho + \sigma_a/\rho + \kappa/\rho$$

where τ, σ_a and κ are the absorption coefficients for photoelectric absorption, Compton absorption, and pair production, respectively, and ρ = density of the medium. Accordingly, the sum of these absorption coefficients was calculated for a number of elements of interest. Three relations were used in these calculations.

1. The Klein-Nishina formula for the Compton absorption coefficient (*4*).

2. The following empirical equation from Lea (*4*) for C,N and O

$$\frac{\tau}{\rho} = 0.0089\,\frac{Z^{4.1}}{A}\,\lambda^{3.05}$$

3. The following relationships among the various elements (*5*)

$$\frac{\tau}{\rho} = \frac{\tau_s}{\rho_s}\,\frac{A_s}{A}\,\frac{Z^{4.1}}{Z_s^{4.1}}$$

$$\frac{\sigma}{\rho} = \frac{\sigma_s}{\rho_s}\,\frac{A_s}{A}\,\frac{Z}{Z_s}$$

$$\frac{\kappa}{\rho} = \frac{\kappa_s}{\rho_s}\,\frac{A_s}{A}\,\frac{Z^2}{Z_s^2}$$

In these equations aluminum was taken as the reference element.

In this manner compatible curves were obtained for the elements of

* Throughout this paper the term "air equivalence" will be taken to mean proportionality between the energies absorbed in a given thickness of crystal and the energies absorbed in an equivalent thickness of air. In general, the absolute values of the energies absorbed will be quite different.

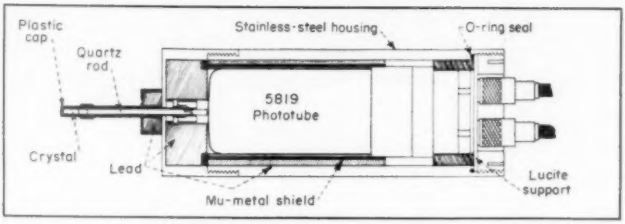

FIG. 2. Scintillation-counter housing

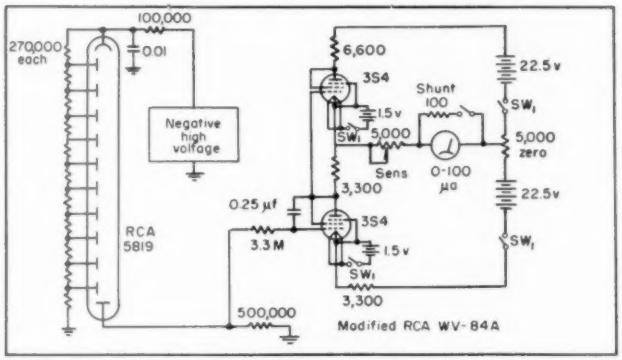

FIG. 3. Electronic circuit used in experiments

interest. These curves were then compounded to give total mass-absorption curves for the various molecular compounds. To verify to some extent the curves so obtained, the total mass absorption coefficient μ/ρ was calculated with the help of Compton's equation relating total to Compton absorption (*6*)

$$\sigma = \sigma_a \frac{(m_0c^2 + 2h\nu)}{h\nu}$$

The values of μ/ρ so compounded were in general consistent with the values given by the "Handbook of Physics and Chemistry" (*7*). The mass-absorption-coefficient curve for water is shown in Fig. 1, along with the curve given by Marinelli *et al.* (*8*). The discrepancy at low energies could be resolved, no doubt, by a more rigorous calculation of τ/ρ. However, for our purposes, Lea's approximation is sufficient.

A number of solid and liquid scintillators were investigated to ascertain how closely the mass absorption coefficients of these compounds approximated those of air. It may be expected that at energies between about 250 kev and 10 Mev, for the light elements, the principal mode of absorption will be by the Compton process. Since the Compton mass absorption coefficient varies among the elements as Z/A, carbon, nitrogen, and oxygen should exhibit similar mass absorption coefficients. Hence scintillation crystals which are predominately carbon by weight (e. g., anthracene, napthalene) should be relatively air equivalent in this region.

Below 250 kev the photoelectric effect becomes the dominant factor. Since it varies as $Z^{4.1}/A$, there are large differences between the total absorption coefficients of carbon, nitrogen, and oxygen. It is in this low-energy region that major difficulties arise in finding natural air-equivalent scintillators, and one must resort to devious methods to simulate air equivalence.

One procedure is based on the use of two different crystals as the detecting element. There are, on the one hand, scintillating media in which the ratio of the medium and air absorption coefficients decreases with decreasing energy (as is the case with anthracene and napthalene in the region below 250 kev). On the other hand, there are media in which the ratio of the medium and air absorption coefficients increases with decreasing energy over the same energy range (as is the case with thin calcium-tungstate and potassium-iodide crystals). This suggests the possibility of combining two crystals of different composition so that the ratio of the medium and air absorption coefficients remains essentially invariant over a given energy range.

Another possible procedure is based on adjustment of the physical dimensions of the crystal to obtain the desired absorption characteristics. For example, in the region below 70 kev, the absorption coefficient for air rises sharply with decreasing energy (mirroring dominance of the photoelectric effect). In this same energy region, the absorption coefficients for calcium tungstate and potassium iodide also increase with decreasing energy but at a far more rapid rate than the coefficients for air.

The energy absorbed in a small volume of air will be proportional to the beam intensity and the function $(1 - e^{-\mu x})$ where x is the crystal thickness. Since μ is extremely small for air (mainly because of its low density), the quantity $(1 - e^{-\mu x})$ is essentially equal to μx. For a given x, the ratio of absorption coefficients at E_1 and E_2 kev ($E_2 > E_1$) will be μ_{E_1}/μ_{E_2}, which will be equal to the ratio of energies absorbed. For heavy elements, however, the approximation $(1 - e^{-\mu x}) = \mu x$ is no longer valid, even for small x, because μ itself is quite large. The ratio of energies absorbed at E_1 and E_2 for the heavy crystal will be proportional to

$$\frac{(1 - e^{-\mu_{E_1} x})}{(1 - e^{-\mu_{E_2} x})}$$

Now if

$$\left|\frac{\mu_{E_1}}{\mu_{E_2}}\right|_{\text{air}} \leq \left|\frac{\mu_{E_1}}{\mu_{E_2}}\right|_{\text{scintillating medium}}$$

then it is possible to select x in such a manner that the equation

$$\left|\frac{\mu_{E_1}}{\mu_{E_2}}\right|_{\text{air}} = \left|\frac{1 - e^{-\mu_{E_1} x}}{1 - e^{-\mu_{E_2} x}}\right|_{\text{scintillating medium}} \quad (1)$$

is satisfied. Further, if E_2/E_1 is not

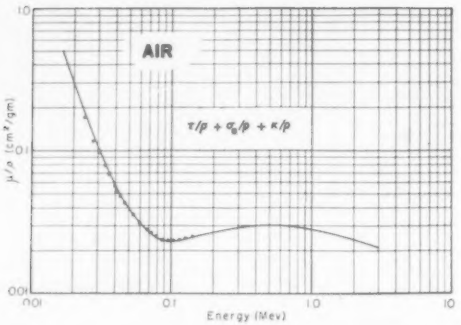

FIG. 4. Sum of the mass absorption coefficients of air as a function of the quantum energy. Plotted points represent ratio of Victoreen-chamber readings to $CaWO_4$ scintillation readings as function of effective energy.

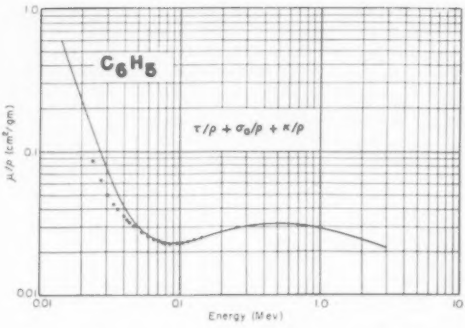

FIG. 5. Sum of the mass absorption coefficients of C_6H_5 as a function of the quantum energy. Plotted points represent ratio of anthracene, etc, scintillation readings to those for $CaWO_4$ as a function of effective energy

too large, then it can also be shown that

$$\mu_{air} \cong (1 - e^{-\mu x})_{\text{scintillating medium}}$$

over the range E_1 to E_2.

One apparent difficulty with this method is the fact that the value of x required by Eq. 1 is often too small to be achieved physically without extreme difficulty. For example, the use of a potassium-iodide crystal over the range from 100 to 30 kev is governed by the following equation

$$4.78 = \frac{1 - e^{-109x}}{1 - e^{-4.07x}}$$

which is satisfied by $x = 0.0575$ cm. It would be very difficult to cut a crystal to this exact size. For a heavier element such as calcium tungstate, the difficulty would be even more pronounced.

There is, however, a method of overcoming this difficulty. If it were possible to incorporate a powdered form of some heavy crystal into a bonding resin transparent to the visible fluorescences, the crystal thickness could be made effectively as small as desired simply by incorporating a desired amount of the powdered crystal into the medium. This procedure has been found to be practical as will be demonstrated later.

Experimental Apparatus

The apparatus employed for these experiments consisted of an RCA 5819 phototube enclosed in a stainless-steel housing. The tube was shielded from magnetic fields by the use of a mu-metal shield,* and from stray radiation by lead sleeves inside and outside the magnetic shield, as well as by the stainless-steel housing itself. For these experiments the shielding was quite adequate since the housing itself was never placed in the direct radiation beam. The crystal was housed inside a small plastic cap, the light being piped to the phototube by means of a quartz rod.

It should be mentioned that the quartz rod itself scintillates under the action of intense radiation. These scintillations are quite small and are completely negligible in the presence of an energetic scintillating crystal. However, if one deals with an inefficient scintillating material, one must make certain that a sizeable contribution is not obtained from the quartz rod.

A cross sectional view of the housing is shown in Fig. 2. Originally, some attention was given to the effect of the plastic cap on the measurements. Rough calculations indicated that if the cap were made of a material itself somewhat air equivalent, the contributions made by the cap could be neglected. Unlike the air-wall chamber, where an appreciable portion of the absorption took place in the chamber walls, the scintillation counter was not greatly affected by the wall thickness of the cap. This was borne out by experiments where the wall thickness of the cap was altered considerably without a measurable change in the scintillation-counter readings. Likewise, the placement of a thin aluminum foil around the crystal to increase the light-collecting efficiency did not seem to have any measurable effect on the reading.

In practice, the wall thickness of the cap was approximately 0.5 mm, which gave it reasonable strength and a thickness slightly greater than the range of the most energetic secondary electrons. The crystals were enclosed, except for the top, in a 0.001-in. aluminum foil for the purpose of reflecting light in the direction of the photomultiplier tube.

The electronic circuit consisted of a positive-grounded high-voltage supply† and an electronic microammeter,‡ by means of which the total tube current is read. The microammeter was modified by the addition of a resistance-capacitance integrating circuit to smooth out variations in the meter readings. The electronic circuit is shown in Fig. 3.

Experimental Method

As an approach to validation of the preceding arguments, an attempt was made to verify, at least in part, the shape of the predicted absorption curves. Since the low-energy region, below 250 kev, appeared to be the most critical, our work was carried out in this energy range. A Westinghouse constant-potential installation, providing filtered or unfiltered radiation in the range from 30 to 250 kilovolts, was

* Available from James Millen and Company, Malden, Mass.

† Model 306P, Atomic Instrument Co., Cambridge, Mass.

‡ Model WV 84A, Radio Corporation of America, Camden, N. J.

Operating Ranges Used for X-ray Machine in Experiments

Range	*Filter*	*kvp*	*Half-value layer (mm)*	*Effective energy E_e (kev)*
1	2 mm Cu 1 mm Al	250	2.75 Cu	145
		230	2.35	129
		210	2.04	116
		190	1.75	105
		170	1.45	95
		150	1.20	87
		130	1.00	80
		110	0.80	73
		90	0.63	66
2	0.25 mm Cu 1 mm Al	170	0.95 Cu	78
		150	0.77 Cu	72
		130	0.65 Cu	66.5
		110	0.50 Cu	60
		90	8.0 Al	54
		70	6.25 Al	47
3	no filter	170	5.5 Al	44
		150	5.0	42
		130	4.2	39
		110	3.6	36
		90	2.9	34
		70	2.3	30.5
		50	1.75	27.5
		30	1.2	24.0

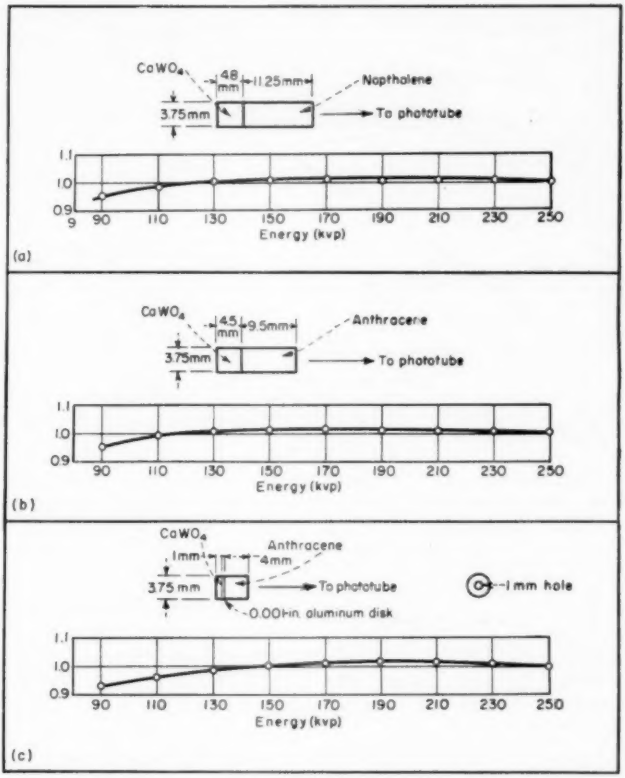

FIG. 6. Ratio of scintillation readings to Victoreen readings for various compound crystals in range 1

used as a source of X-radiation. Half-value-layer measurements were made to determine the effective energy range of the X-ray installation. To cover the full effective energy range completely, the machine was operated over the three ranges listed in the table on this page.

One can obtain the coefficient of absorption from the following relation

$$E = \sum_i I_i(1 - e^{-\mu_i x})$$

where E is the total energy absorbed in the medium of thickness x, I_i is the intensity of the incident quanta having energy $(h\nu)_i$, and μ_i is the absorption coefficient of the absorbing medium for a quantum of energy $(h\nu)_i$. Here μ_i refers to the absorption coefficients involving energy transfer to the absorbing medium, i. e., total absorption coefficient less the Compton scattering. I_i is, in turn, given by

$$I_i = p_i(h\nu)_i$$

where p_i is the percentage of quanta at energy $(h\nu)_i$. Since we will be dealing with a distributed energy spectrum, it is necessary to employ an averaging process for the above quantities to obtain

$$E = I_e(1 - e^{-\mu_e x}) \qquad (2)$$

where I_e represents the effective intensity of the beam, and μ_e the effective absorption coefficient. To determine I_e, it would be necessary to stop all the incident quanta and measure the total energy given up to secondaries. This may be accomplished, experimentally, if $\mu_e x$ in Eq. 2 is made large, in which case the term $e^{-\mu_e x}$ is negligible and

$$E \cong I_e$$

In practice, one may employ a sufficient thickness of a heavy crystal, such as calcium tungstate, to approximate this condition. At 250 kvp, with 2-mm Cu and 1-mm Al filtration, for example, if one uses a calcium tungstate crystal 4 mm thick, one may show that about 98% of the incident radiation is absorbed in the crystal. Thus phototube current readings with this crystal should be roughly proportional to intensity at or below 250 kvp.

Readings were taken over the three ranges shown in the table, the highest reading in each range being set at 100. Since the scintillation meter reading decreased considerably in the lower portion of each range, the operating voltage of the phototube was increased at intervals to provide adequate microammeter deflection. By this means it was possible to obtain a ratio of meter readings from 250 kvp down, the readings being normalized to 100 at 250 kvp.

Equation 2 for air and for those elements whose density is near unity

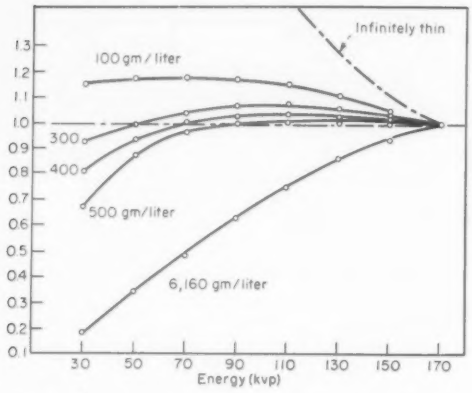

FIG. 7. Ratio of scintillation readings to Victoreen readings for various crystals in range 3

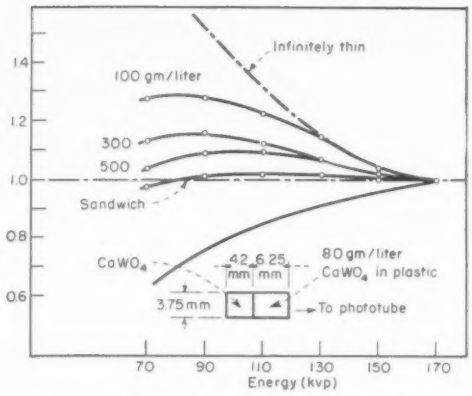

FIG. 8. Ratio of scintillation counter readings to Victoreen readings for various crystals in range 2

may be, for a value of x of the order of a few millimeters, approximated by

$$E \cong I_o \mu_e x \qquad (3)$$

and since x is a constant

$$\mu_e \cong E/I_e$$

I_e has already been determined ratiowise as a function of the effective energy, and E, the energy absorbed by the light crystal, is measured ratiowise by taking scintillation readings over the three energy ranges.

As a result one should obtain the relation that μ_e is proportional to counter reading for crystal divided by counter reading for $CaWO_4$. Figure 4 shows a curve of the calculated absorption coefficients for air on which has been plotted the normalized ratio of the Victoreen readings to the 4-mm-$CaWO_4$ readings as a function of the effective energy.

A similar procedure was used to obtain experimental points for some of the more common scintillators, namely, napthalene, anthracene, stilbene, diphenyl acetylene and terphenyl. Because these compounds are composed of carbon and hydrogen and because carbon represents the major portion of the weight, all of these compounds have been fitted to a composite curve labeled C_6H_5. In other words, within the limits of the measurements, all of these compounds have the same absorption curves. The results for the C_6H_5 group are shown in Fig. 5.

An obvious discrepancy exists at the lower energies. This discrepancy may be explained on the basis of the work done by Hopkins (9), who reported a decrease in the pulse height per energy increment below 125 kev for anthracene. This effect appears to be evident throughout the C_6H_5 group. For the purpose of the work that follows, it is sufficient that the experimental data assumes the general shape of the theoretical curve.

Other liquid and solid scintillators were investigated in the same manner. Some, such as p-diphenyl benzene (terphenyl) in p-dioxane (OCH_2CH_2-OCH_2CH_2), were tried because of their high oxygen content as compared to C_6H_5. Because of the difficulties involved in the handling of the liquid scintillators in a probe-type counter and because of the small light output of most of the liquid scintillators, attempts to use liquid media were finally abandoned.

Simulated Air Equivalence

Inspection of Figs. 4 and 5 shows that the ratio of C_6H_5 to air falls off below 250 kvp while the ratio of $CaWO_4$ to air rises slightly from 250 kvp down.* A crystal was constructed using both napthalene and $CaWO_4$. The physical dimensions are shown in Fig. 6a along with the ratio of the apparent absorption coefficients obtained with this crystal to those of air.

A similar arrangement was employed utilizing anthracene and $CaWO_4$, Fig. 6b. Figure 6c shows a crystal compounded for its small size. The small aluminum washer is used to diminish the light contribution from the thin $CaWO_4$ crystal since the apparent absorption coefficient of this thin crystal rises rapidly with decreasing energy.

In compounding these crystals, theoretical calculations showed that one should have roughly equal contributions from the two crystals. In practice this will depend on the relative light yield, on the transpareney of the upper crystal to light emitted by the lower, on the relative efficiency of the phototube to the light spectra of the two crystals, etc. One can only be guided by previous experience and by trial. All of the crystals of Fig. 6 are essentially air equivalent over range 1.

For the lower energy ranges, an attempt was made to obtain air equivalent scintillators by using the method of crystal sizing. After numerous attempts to cut very small crystals of the proper size, it was decided to try incorporating into a bonding resin material from one of the heavy crystals as a powder. Consequently, a crystalline form of $CaWO_4$ was ground to as fine a powder as possible and mixed with a thermosetting polyester resin† in varying concentrations. After solidification, a series of cylinders about 4

* A crystal thinner than the 4-mm crystal used in obtaining the results of Fig. 4 will show an even greater rise. A round crystal 3.50 mm in diameter was eventually used for the compound crystal.

† The resin employed was obtained from the Castolite Company, Woodstock, Ill., but there is no reason to suppose that similar resins cannot be successfully employed.

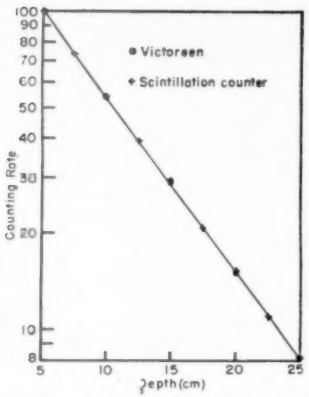

FIG. 9. Readings taken at various depths on central axis of water phantom

mm in diameter and 5 mm in length were cut from the resulting plastics. These were polished and tested for air equivalence over ranges 2 and 3.

Figures 7 and 8 show the results that were obtained for a variety of concentrations of powdered calcium tungstate. The value of 6,160 gm/liter corresponds to a pure calcium tungstate crystal.

The values of the concentration in grams per liter may tend to be somewhat misleading. Actually this represented the amount of powdered $CaWO_4$ added to the liquid resin. Since, however, the $CaWO_4$ is about six times as dense as the polyester resin, it tended to settle out of suspension to an appreciable extent. Care was taken to avoid this settling by using as fine a powder as possible and by agitating the mixture, turning it end over end until it first began to jell. Concentration in grams per liter represented, therefore, a maximum possible concentration, with actual concentration probably somewhat lower.

Figure 7 shows that over the lower part of range 3 a concentration of 100 gm/l is air equivalent to within about 3%, while for the upper part of range 1, a concentration of about 400 or 500 gm/l is essentially air equivalent.

Figure 8 illustrates the results obtained over range 2. Since 500 gm/l is close to the maximum concentration that can be conveniently obtained, a compound crystal was used in this energy range. The final crystal and the apparent absorption ratio are shown in Fig. 8.

To use any of the foregoing crystals to measure dosage in roentgens, it is necessary that the crystal be air equivalent over the energy range involved, or in other words, that the energy range involved fall within the air-equivalent response range of the crystal. It would be outside the limits of this paper to discuss the ramifications involved in this respect, but it is sufficient to say that for peak voltages less than 250 kv, a crystal may in general be used to measure isodose curves for any E_r within the upper range of that crystal. This is due to the fact that for these energies the effective energy at a depth in a water phantom is less than the effective energy in air because of multiple scattering within the phantom. The reader is referred to a recent paper by Greenberg and Wilson (*11*) for further information concerning this effect.

As an illustration let us consider the crystal shown in Fig. 6c, and its use at 250 kvp, with 2-mm Cu, 1-mm Al filtration. To compare this crystal to the Victoreen chamber, readings were taken on the central axis of a water phantom 40 cm on each side at a number of depths. The readings corrected for inverse-square-law loss are shown in Fig. 9. The Victoreen readings were taken by encasing the chamber in a thin rubber covering and inserting the whole into the phantom. The procedure is somewhat tedious. With scintillation counters the task is relatively simple since the counter may be mounted on a traverse above the phantom, the probe being the only extension into the water phantom from the counter.

Summary

Over limited energy ranges air-equivalent scintillation counters may be constructed for almost any energy from 20 kev up to about 10 Mev. The means of simulating air equivalence consist of (1) using natural materials (C_6H_5 above 250 kev),‡ (2) compounding two or more crystals (C_6H_5 and $CaWO_4$ from 250 kev to 70 kev) and (3) sizing of crystals combined with compounding crystals ($CaWO_4$ in plastic below 100 kev). Air-equivalent crystals so constructed may be used to determine isodose curves if the energies involved lie within the effective range of air equivalence.

The advantages of the scintillation dosimeter over the Victoreen chamber are:

1. Direct readings of instantaneous rather than integrated dosage are provided.

2. The small size of the probe and detecting element enables one to obtain more nearly point measurements.

3. The sensitivity per unit volume of the scintillation dosimeter is considerably higher than that of the Victoreen chamber. (The probe may be used, for example, *in vivo*, or in solution without any special precaution.)

In general, the instrument appears quite stable in use, the variation in repeated readings being at most $\pm 2\%$. The apparatus is allowed several hours to warm up before use since there is some initial drift in the high voltage and microammeter zero. Over a period of time the signal-to-noise ratio of a given phototube appears to decrease slightly, but since most readings are taken with no background, this causes no difficulty. The sensitivity of a particular arrangement will depend on the crystal size, the length and diameter of the light pipe, and the phototube voltage. Generally, a sensitivity of one roentgen per minute full scale deflection can be achieved without any objectionable phototube background.

* * *

This work is based on work performed under contract At(11-1)-85, Project 3, between the U. S. Atomic Energy Commission and Washington University, St. Louis, Missouri.

‡ Although no investigation of the higher energy range has been carried out in this laboratory, the work of Smeltzer (*10*) tends to confirm the theoretical predictions made on the basis of our work. Smeltzer is now in the process of investigating the high-energy region with a 50-Mev betatron.

BIBLIOGRAPHY

1. W. K. Jentschke, F. S. Eby, C. J. Taylor, M. E. Remley, P. G. Kruger, *Phys. Rev.* **83,** 1 (1951)
2. R. Hofstadter, J. A. McIntyre, *Phys. Rev.* **78,** 619 (1950)
3. J. A. McIntyre, R. Hofstadter, *Phys. Rev.* **78,** 617 (1950)
4. D. E. Lea, "Action of Radiations on Living Cells" (Cambridge University Press, Cambridge, England, 1946)
5. C. Goodman, ed., "Science and Engineering of Nuclear Power," p. 41 (Addison Wesley Press, Inc., Cambridge, Mass., 1947)
6. K. Compton, S. Allison, "X-rays and Electrons" (D. Van Nostrand, New York, N. Y., 1926)
7. "Handbook of Chemistry and Physics," 31st ed. (Chemical Rubber Publishing Co., Cleveland, Ohio, 1949)
8. L. D. Marinelli, E. H. Quimby, G. J. Hine, *Am. J. Roentgenol. Radium Therapy* **59,** No. 2, 260 (1948)
9. J. I. Hopkins, *Rev. Sci. Instr.* **22,** 29 (1951)
10. J. C. Smeltzer, *Rev. Sci. Instr.* **21,** 669 (1950)
11. J. R. Greening, C. W. Wilson, *Brit. J. Radiology* **24,** 605 (1951)

Molded Multi-Crystalline Stilbene For Scintillation Counting

For applications dependent upon the integrated light output of the phosphor, multi-crystalline stilbene is as satisfactory as single-crystalline stilbene up to a thickness of about 1½ cm. Preparation of molded multi-crystalline stilbene is described

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THE WIDESPREAD INTEREST in applications of scintillation counting has stimulated investigations of scintillation phosphors of many different types —both inorganic and organic crystals and organic liquid and plastic phosphors. Very recently, molded multi-crystalline stilbene has been developed which combines some advantages of both crystalline and plastic phosphors. The relative advantages and limitations of each group are summarized in Table 1.

Preparation of Crystals

Catalog-grade Eastman stilbene that had been purified by two recrystallizations from ethyl acetate was used in preparation of all the phosphors used in these studies. Single-crystalline stilbene was grown slowly from the melt in an electronically operated furnace.

The molded multi-crystalline stilbene was prepared by melting crushed stilbene crystals in an aluminum mold and allowing the mold to cool at room temperature. There is a sufficient differential in contraction of the crystallized stilbene and the aluminum that the molded mass of stilbene is readily removed by tapping the mold. The multi-crystalline stilbene is slightly translucent to visible light and contains some crystals that are as large as ¼ in. on a side.

Phosphors prepared from Eastman stilbene twice recrystallized from ethyl acetate, exhibited twice the scintillation light output of a phosphor prepared from the unrecrystallized material. Although infrared spectra are generally considered a very sensitive criterion of the purity of organic compounds, it apparently is not as sensitive a criterion as the scintillation light output, since identical infrared spectra were obtained with the unrecrystallized and twice-recrystallized stilbene. Four recrystallizations from ethyl acetate did not increase the scintillation light output over that of the twice-recrystallized material.

Requirements for preparation. The major requirements which an organic crystalline scintillating material must meet in order that it can be prepared in multi-crystalline masses by the simple method described here are:

1. The melting point should be above room temperature, but not much higher than 150°–160° C.
2. The material should not be readily oxidized in the molten state.

Attempts to prepare multi-crystalline terphenyl and anthracene by these methods failed because their melting points are so high (over 210° C) that, when melted, the materials discolored due to oxidation. Even more important, crystallization occurred so rapidly that only finely powdered crystals resulted. Efforts to increase the size of crystals by allowing the mold to cool slowly in an oven did not result in significantly larger crystals.

Methods of Measurement

The comparison of the scintillation properties of the various forms of stilbene (single-crystalline, multi-crystalline, and powdered) was made by measuring the total integrated response of the phosphors to external radiation. The experimental setup consisted of an RCA 1P21 photomultiplier tube with regulated negative high-voltage supply, a cathode-follower circuit, and an indicating microammeter which measured the current developed across the grid resistor of the cathode follower. The deflection of the microammeter was thus proportional to the intensity of radiation.

Relative light intensity was obtained as a function of the mass of the phosphor with the cross section of the phosphors constant (¾ × 1 in.). A special aluminum container of this same cross section with horizontal spacers to vary the amount of the material was used for the powdered stilbene.

Most of the results were obtained with a Co^{60} gamma source at a fixed distance from the phosphors, usually 30 cm. Measurements were also obtained with a polonium alpha source

to assist in determining an effective absorption coefficient of the single-crystalline and multi-crystalline stilbene for their own emitted light.

Data Obtained

Figure 1 is a plot of light intensity versus mass under Co^{60} gamma irradiation for several different slugs of twice-recrystallized multi-crystalline stilbene. The variation in results from slug to slug gives an indication of the spread to be expected in growing individual slugs of multi-crystalline stilbene. This spread—about $\pm 10\%$ at 10 gm—can probably be attributed to differences in sizes and disposition of the component single crystals in the multi-crystalline mass.

In Fig. 2 are plotted the data obtained on the single-crystalline, multi-crystalline, and powdered stilbene under gamma irradiation. The curves at the low masses are surprising in that the multi-crystalline mass seems to generate more light than the single crystal up to a thickness of 1.5 cm. As would be expected at larger masses, the single crystal generates more light per unit mass. The crushed stilbene yields as much light as the single crystal up to 0.5 cm, but beyond that the crushed material has effectively infinite thickness for its own emitted light. Similar type curves on naphthalene and phenanthrene have been reported by Kallmann (*2*) who gives plots of intensity versus thickness for a vacuum-sublimed mass, for the imperfect crystal obtained by melting this mass, and for the pulverized crystal.

TABLE 1—Advantages and Limitations of Different Types of Phosphors

Type	*Advantages*	*Limitations*
Single crystal	Largest pulse size.	Large crystals limited by cost and difficulty in growing.
Solution	Relatively large pulse. Easy to prepare. Inexpensive.	Liquid state limits some applications.
Plastic	Only material that permits large size phosphors to be prepared. Can be machined into unique shapes. Inexpensive except for machining operations.	Smallest light pulse but recently developed plastic phosphor reports light pulse equivalent to solution phosphors (*1*).
Molded multi-crystalline stilbene	Relatively high light efficiency. Total light output equal to single crystalline stilbene in thickness up to 1.5 cm. Can be molded directly to any desired shape.	Approximately same pulse size as liquid scintillators.

Kallmann's results also show the powder and crushed crystal giving more light at small thicknesses than the single-crystal material. He suggests that internal quenching effects from distortions in the single crystal may be important.

Comparative measurements on integrated light output and pulse height of terphenyl-polystyrene phosphor (*3*) and multi-crystalline stilbene were made. Under Co^{60} gamma radiation, the multi-crystalline stilbene exhibited an integrated light output eight times that obtained from the plastic phosphor of the same mass. In Fig. 3 plateau curves of counting rate versus voltage are illustrated for single-crystalline stilbene, multi-crystalline stilbene, and the plastic phosphor under Co^{60} ($\sim$1.2 Mev) and Se^{75} ($\sim$0.2 Mev) gamma radiation.

A slightly different experimental arrangement was employed with the single-crystalline stilbene, and thus these results are not directly comparable to those of the multi-crystalline and plastic phosphors. The plateau

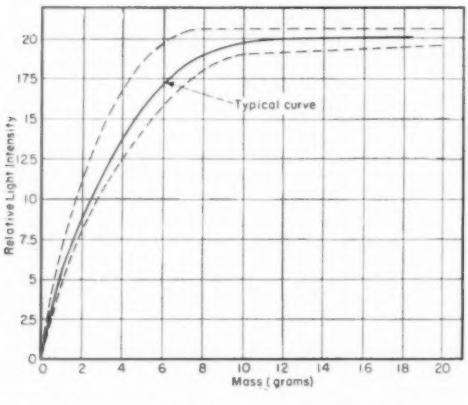

FIG. 1. Light intensity as a function of mass for multi-crystalline stilbene. Dotted curves represent spread obtained on five slugs

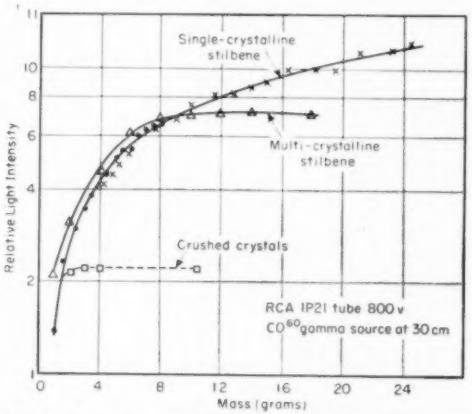

FIG. 2. Comparison of single-crystalline, multi-crystalline, and crushed stilbene

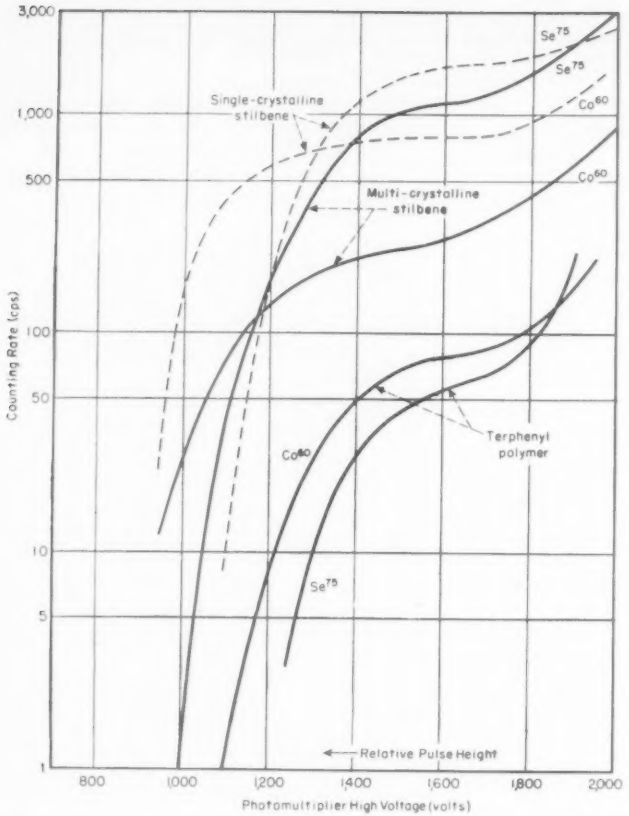

FIG. 3. Comparison of single-crystalline stilbene, multi-crystalline stilbene and terphenyl-polystyrene plastic

curves obtained in Fig. 3 can be expressed in terms of relative pulse height, with the scale increasing to the left since larger scintillation pulses can be detected at lower photomultiplier tube voltage, that is, at smaller gain. Table 2 summarizes the results on the comparative counting rates and pulse heights.

Theoretically, the shapes of the curves for relative light intensity as a function of mass under gamma radiation can be given quite simply by an expression of the form:

$$I_L = K[\mu_s/(\mu_e - \mu_s)][e^{-\mu_e x}(e^{(\mu_e-\mu_s)x} - 1]$$

where I_L = relative light intensity, μ_s = absorption coefficient for gamma radiation per cm, μ_e = effective absorption coefficient of material for its own emitted light per cm, and x = length of phosphor.

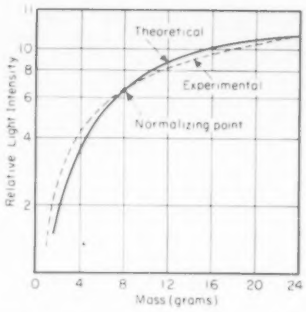

FIG. 4. Theoretical distribution for single-crystalline stilbene

Figure 4 shows a comparison of the experimental and theoretical curves obtained on the single-crystalline stilbene. For the simplifying assumptions made, the agreement is quite good. Although not included, similar agreement was found for the multi-crystalline stilbene.

The effective absorption coefficients of the various phosphors for their own emitted light as obtained by fitting the theoretical and experimental curves are as follows:

Single-crystalline stilbene:

$$\mu_e = 0.20 \text{ cm}^{-1} (K \simeq 82\%/\text{cm})$$

Multi-crystalline stilbene:

$$\mu_e \simeq 0.80 \text{ cm}^{-1} (K \simeq 45\%/\text{cm})$$

From optical data taken on a Beckman spectrophotometer, the absorption coefficient for a single crystal of stilbene at 4,000 Å is ~84%/cm, which is in good agreement with the above value of ~82%/cm. The average wavelength of light emitted by stilbene under external excitation is 4,000 Å.

* * *

The assistance of Katherine A. Blotzer and David Forrant in collecting much of the experimental data is gratefully acknowledged.

TABLE 2—Comparative Counting Rates and Average Pulse Heights under Co^{60} and Se^{75} Gamma Radiation

Phosphor	*Counting rate* Co^{60}	Se^{75}	*Average pulse height* Co^{60}	Se^{75}
Terphenyl-polystyrene plastic	1	1	1	1
Multi-crystalline stilbene	3	20	3	1.5
Single-crystalline stilbene	—	—	4.5	1.7

BIBLIOGRAPHY

1. L. Pichat, Y. Koechlin, *J. de Chimie Physique*, **48**, 225 (1951)
2. H. Kallmann, Scintillation phosphors, at Scintillation Counter Symposium (Oak Ridge National Laboratory, Oak Ridge, Tenn., June 3–4, 1949)
3. M. G. Schorr, F. L. Torney, *Phys. Rev.* **80**, 474 (1950); also M. G. Schorr, E. C. Farmer, *Phys. Rev.* **81**, 891 (1951)

Economics of Steam-Temperature Selection in Nuclear Power Plants

Optimum power-station steam temperatures must be determined in conjuction with the design of the nuclear reactor. The range 600–800° F is the most economical where heat is supplied by a dual purpose reactor

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AN EVER-RECURRING question in the design of power plants that use fissionable material as fuel is "How high a steam temperature must be used to make the plant economically feasible?"

In an attempt to answer this question, an analysis has been made in terms of cost of optimum steam temperatures for use in electric power stations.

The most economical steam temperature turns out to be in the range 600–800° F, in situations where heat is supplied at no expense to the power-plant. This would be the case where the cost of a nuclear reactor to supply the heat would be subsidized by sale of the fissionable products formed. The results may be extended to cases where part or all of the cost of the nuclear fuel is chargeable to the account of the electric generating plant.

The method of analysis used is the separation of the cost of electric power as produced at the power station (not including distribution costs) into three component parts, fuel cost, operation cost, and investment cost. These are studied separately, primarily as a function of top steam temperature in the plant; the results are then synthesized into a combined cost per unit of electric power.

The analysis has been based mostly upon statistical data, and therefore many of the effects of unstated local variables could not be eliminated; but it is believed that the conclusions reached are basically sound. The quantitative accuracy of the results may be improved at a later date when more specific data are obtainable.

Fuel Cost

The largest single item in the cost of electricity produced in steam-electric plants is the fuel cost, and this item is also the one most affected by the steam temperature.

The specific fuel cost per unit of power produced may be calculated by the formula

$$C_f = \frac{3{,}413\,F}{100{,}000\,E} \qquad (1)$$

where C_f = specific fuel cost in mills/kwh, F = unit fuel price in cents/

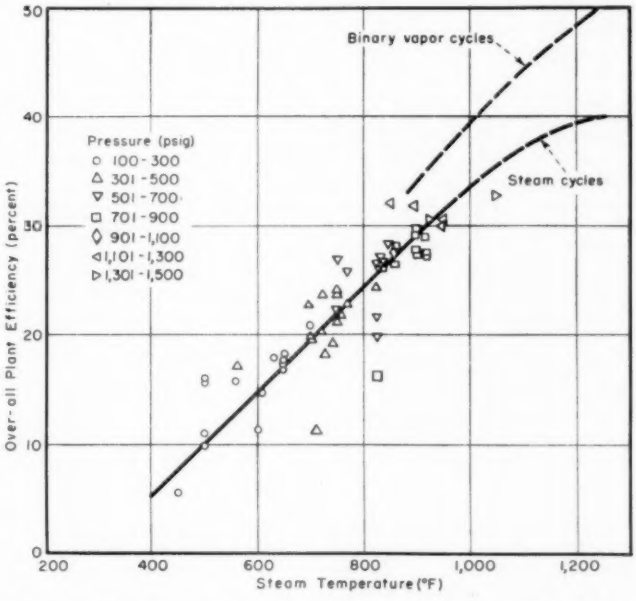

FIG. 1. Over-all efficiencies of steam-electric plants (1, 2, 3). The probable future trends are shown by the dotted lines

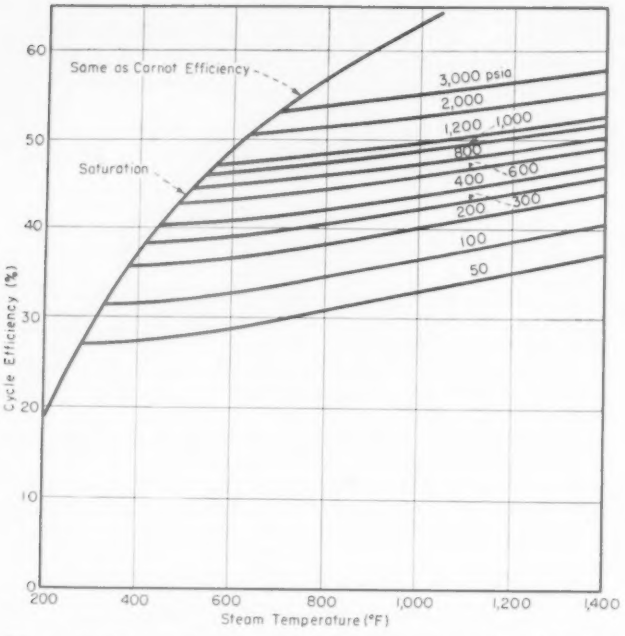

FIG. 2. Ideal regenerative-cycle efficiencies for steam-electric plants for various turbine inlet pressures (*4, 5, 6*)

million BTU, E = over-all plant efficiency, and 3,413 = thermal equivalent of electricity in BTU/kwh.

The over-all efficiency of several plants has been plotted against temperature in Fig. 1, with steam pressure as a secondary variable. Only plants having all boilers operating at the same temperature have been included. These values have been taken from available data (*1, 2, 3*) in which they are stated in terms of the net heat rate, BTU per kilowatt-hour, which is equal to 3,413 divided by the efficiency.

Probable future trends in over-all efficiency have been estimated with the aid of Fig. 2, which gives the ideal efficiencies of regenerative steam cycles at various pressures and temperatures. It is evident that further increases in temperature over 1,000° F cannot result in as great improvements in efficiency as were obtainable by increasing the temperature from 500° F to 1,000° F, because the steam pressures soon will become limiting. The use of a binary cycle such as the mercury-steam cycle enables the plant to operate closer to the Carnot efficiency without the disadvantages of extremely high steam pressures.

Figure 2 was plotted from data given by Selvey, Knowlton, and Hartwell (*4, 5*), with extra points calculated by the methods of Salisbury (*6*). It is intended to serve as a reference with which the data in Fig. 1 can be compared. The condenser pressure is assumed to be 1 in. Hg, which is a somewhat better vacuum than most plants maintain. If the back pressure were 2.5 in. Hg, the efficiencies would be lowered about 3%.

The ratio of the efficiency of each plant divided by the ideal efficiency at the rated temperature and pressure is called the performance ratio, and gives a measure of the thermal and mechanical efficiencies of the equipment in the plant. These ratios have been plotted in Fig. 3, and it is evident that few plants obtain more than 65% of their ideal efficiencies.

Random variables in these data are the condenser pressure, the arrangement of the cycle (reheat, regenerative, etc.), the thermal and mechanical efficiencies of the components, and the miscellaneous steam usage. Furthermore, the efficiencies are yearly averages, and include operation at less than full load, as well as heat used in keeping the boilers hot and ready, which is particularly significant for the low-temperature plants used for stand-by service.

The severe falling off of the performance ratio at low steam temperatures is not necessarily indicative of the performance of a low-temperature plant which could be designed for continuous service with the benefit of modern improvements in the state of the art. Selvey and Knowlton (*4*) and Skrotzki and Vopat (*7*) indicate that a ratio of about 0.60 can be maintained down to temperatures at least as low as 550° F. Table 1, taken from Selvey and Knowlton (*4*) shows what factors make up this performance ratio.

If the unit fuel price is expressed in terms of cents per million BTU of heating value, the comparison of different fuels is simplified. Average prices of fuels in different regions of the United States are given in Table 2 for the year 1947 (*1*).

Where no figures are given in Table 2, it is generally because the price is so high in that region that no plants listed use that fuel. Therefore, it would be incorrect to assume that the national average price of gas is 14 cents per million BTU. It is evident, however, that fuel prices range from 10 to 40 cents, depending on the locality.

The fuel costs per unit of electrical output are then as shown in Table 3. Even if the efficiencies at low temperature were higher than those in the table, as discussed before, the conclusions reached in the final section of this paper would not be changed.

Operating Cost

The operating cost of a steam-electric power plant, exclusive of fuel cost, is roughly divided as follows (*5*)

Running expense	60–70%
Boiler maintenance	10–20%
Turbo-generator maintenance	5–10%
Miscellaneous	Balance

Although not usually considered as fixed in the same sense as the investment cost, it is nevertheless true that the operating cost continues year after year practically regardless of the electrical load on the station. This is so because even the plants which

run at a low average percentage of their rated capacity are generally held in hot reserve, ready to supply power at a moment's notice. Thus the wages of the supervisors and operators do not vary with load factor.

In view of the above arguments, it would be expected that a better correlation of data would be obtained if yearly operating costs per kilowatt of station rating were plotted against temperature, rather than the specific operating cost in mills per kilowatt hour. One can be transformed into the other by the formula

$$C_0 = \frac{1{,}000}{8{,}760} \times \frac{P}{L} \qquad (2)$$

where C_0 = specific operating cost in mills/kwh, P = yearly operating cost in dollars/yr per kw rating, L = average, load factor, fraction of rated capacity, and 8,760 = number of hours in a year.

Operating costs have been plotted both ways in Figs. 4 and 5, with lines of constant load factor added to Fig. 5. Plants smaller than 20,000 kw rating have been omitted because their costs are inordinately high, but study of the available data has shown that the yearly operating costs per kilowatt rating are essentially invariant with size for the larger plants.

It is apparent from Fig. 5 that low-temperature plants generally have lower load factors than high-temperature plants. The load factor is not intrinsically a function of temperature, but there is an understandable tendency of power networks to have their efficient high-temperature plants carry the greater part of the load.

In an analysis to determine the economic temperature of a new plant, a line of constant load factor on Fig. 5 should be used, rather than the statistical experience line. Thus the increase in operating cost with decreased temperature will be much less than would be otherwise predicted. Furthermore, a new plant, even though of low temperature, would undoubtedly have more labor-saving equipment than many of the older low-temperature plants, which would flatten the cost line even more.

Investment Cost

That part of the cost of power which is attributable to the physical worth of the plant is called the investment

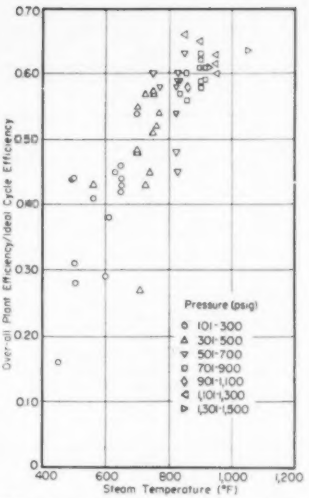

FIG. 3. Performance ratios for steam-electric plants.

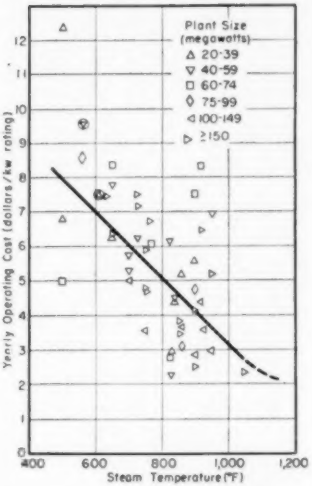

FIG. 4. Yearly operating costs for steam-electric plants (1). Circled points are 1940 data corrected to 1947

TABLE 1—Factors That Make Up Performance Ratio

Factor	*Performance ratio*
Turbine efficiency	0.83
Cycle design*	0.96
Operating efficiency†	0.97
Mechanical and electrical efficiency	0.97
Boiler efficiency	0.88
Miscellaneous losses	0.94
Product	0.62

* Due to a finite number of regeneration stages being used.

† Due to part-load operation, dirty blading, and off-design regenerator temperatures.

TABLE 2—Fuel Prices in the United States for the Year 1947

	Cost (cents/million BTU)		
Region	*Coal*	*Oil*	*Gas*
New England	34	34	—
Eastern	28	35	—
Great Lakes	21	42	12
Southern	27	33	—
Upper Midwest	20	40	14
Lower Midwest	—	22	8
Mountain	20	—	12
Southwest	—	32	22
Northwest*	—	—	—
Averages	26	34	14

* Chiefly hydro-electric power.

TABLE 3—Cost of Fuel

Top steam temperature (° F)	*Approximate over-all efficiency**	*Cost (mills/kwh)*		
		Using 10-cent fuel	*Using 20-cent fuel*	*Using 30-cent fuel*
400	0.05	6.83	13.66	20.49
500	0.10	3.41	6.82	10.23
600	0.15	2.30	4.60	6.90
700	0.20	1.75	3.50	5.25
800	0.24	1.40	2.80	4.20
900	0.29	1.18	2.36	3.54
1,000	0.34	1.00	2.00	3.00

* These values are from Fig. 1.

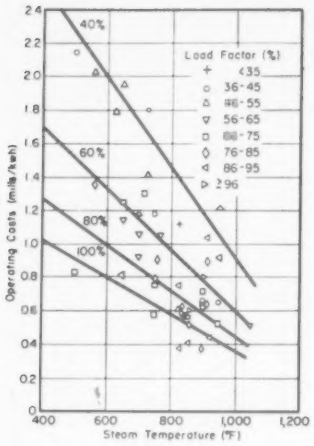

FIG. 5. Specific operating costs for steam-electric plants (*1, 3*). Load-factor lines are calculated from the mean line of Fig. 4

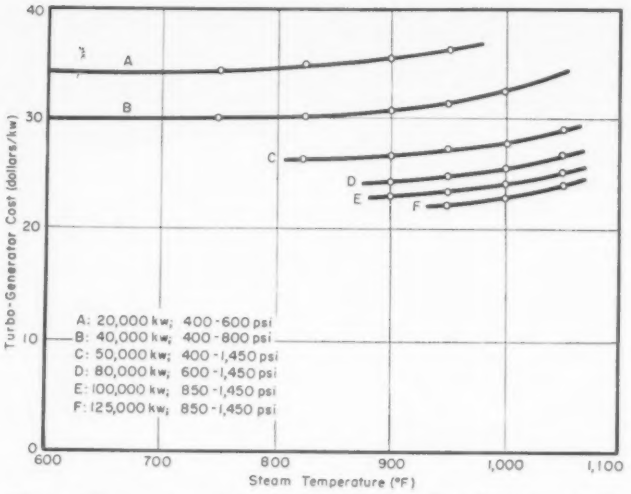

FIG. 7. Turbo-generator costs for steam-electric plants. The turbines have 1-in. Hg absolute exit pressure

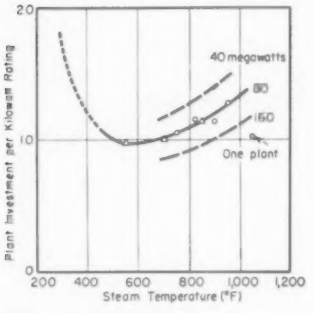

FIG. 6. Relative investment for steam-electric plants (*1, 3, 7*). Circled points are corrected for price index at time of construction; each point represents several plants. Dotted line is estimate based on relative sizes of low-temperature equipment

TABLE 4—Analysis of Investment in a Steam-Electric Power Plant

Steam Temperature (°F)	550	700	850
Steam Pressure (psia)	215	415	915
Efficiency	0.213	0.253	0.284
Performance Ratio	0.576	0.608	0.602
Turbo-generator cost (dollars/kw)	21.5	23.0	25.0
Condensing Equipment (dollars/kw)	13.0	12.0	10.0
Electrical Equipment (dollars/kw)	10.0	10.0	10.0
Auxiliary Equipment (dollars/kw)	8.0	9.0	12.0
Boiler Equipment (dollars/kw)	15.6	16.5	22.5
Total Cost* (dollars/kw)	68.1	70.5	79.5
Relative Cost	0.97	1.00	1.13

* The prices shown here are out of date and should be used for relative values only.

cost, and it includes the interest, depreciation, insurance, and taxes. Sometimes the term "fixed cost" is used because these expenses continue regardless of the power produced.

The specific investment cost per unit of power is related to the total investment by the formula

$$C_1 = \frac{1,000}{8,760} \times \frac{Ir}{L} \qquad (3)$$

where C_1 = Specific investment cost in mills/kwh, I = investment in dollars/kw rating, L = average load factor, fraction of rated capacity, and r = yearly rate of interest, depreciation, etc., (this is usually about 15%) (*3, 7*).

Prediction of the investment required per kilowatt of rating is difficult to determine from a statistical analysis because of the many factors involved, few of which are stated in the data. Some of these are

1. Economic conditions at the time of construction.
2. Local climate as it affects the need for indoor equipment.
3. Local labor and transportation costs.
4. Expense of obtaining cooling water.
5. Fuel handling facilities required.
6. The degree to which modern labor-saving equipment is used.
7. The size of the plant.

Regardless of these unknowns, an analysis of the costs of several plants (*1, 3*) has been made, each cost being corrected for the wholesale price index prevailing in the year of construction. These data were further substantiated by three points taken from an example given by Skrotzki and Vopat (*7*), and the results are given in Fig. 6.

It was necessary to reduce the data to a relative scale, making unity the value of a 700° F plant, in order to bring the data of Skrotzki and Vopat (*7*) into line with that from the other sources (*1, 3*). The average size of the plants included was about 80 megawatts. Lines on Fig. 6 show the approximate effect on investment of building larger and smaller plants.

The absolute value of the investment is difficult to determine in these times of unstable prices, but a value of $170.00 per kilowatt for a 700° F plant is about average for the year 1947, which is the base year for all the other costs in this analysis (*3*).

The costs of the various elements of a steam power plant may be divided roughly as follows (*3*)

Boiler plant equipment	35%
Turbo-generators	25%
Electrical equipment and buildings	25%
Miscellaneous	15%

Outdoor boilers, which can be used if the local climate permits, cost about 30% of the total plant, whereas indoor boilers come to about 40% of the total plant cost.

No information on the cost of equipment for low-temperature installations was available, so an estimate was made based on the increases in the sizes of the components necessary to handle low-temperature and pressure steam.

At 300° F, the weight flow of steam would be at least twice what it would be at 1,000° F for the same power. Furthermore, because of the lower pressure associated with operation at 300° F, the specific volume of the steam leaving the boiler would be about six times as great, so the steam space in the boiler and piping might be as much as twelve times as large as in a 1,000° F plant. The turbine size would depend on the condenser pressure and steam flow. Thus, the size would be more than doubled for the same condenser pressure. But if some sacrifice in efficiency were accepted, the need for increased turbine size could be offset by increases in the selection of the condenser pressure. The sizes of the electrical equipment and of the buildings need not change significantly with steam temperature. Because of the lower efficiency, the heat rejected to the cooling water would be greater, requiring a more expensive cooling system.

It was on such reasoning as the above that the lower end of the curve of Fig. 6 was estimated, and it is believed that the estimated cost, if it is in error, is too low rather than too high.

The rise on the high-temperature end of the curve is probably attributable to the better materials and workmanship that must go into high-temperature plants. However, at least one plant was built for 1,050° F at no higher a cost than a 700° F plant, so the curve shown is not the final word. This plant had a semi-outdoor boiler, which helped to reduce the costs somewhat, and it was also a large plant, having turbo-generators of over 100,000 kw rating each.

Turbo-generator costs (Fig. 7) show the rise in cost of high-temperature units, and also the savings possible by the use of large units. These costs apply only for the pressures stated on the figure. Turbo-generators having higher exit pressures, although smaller, cost almost as much as those that discharge into a vacuum, because a large part of the expense is for the generators and for the controls, bearings, and other components not dependent on the steam exit dimensions. Atmospheric-exit turbines cost about 85% as much as those shown in Fig. 7.

When specific data are available, an analysis of the investment costs may be made in the manner shown in Table 4 (*7*).

Combined Costs

The specific costs of power for plants having 90% load factor and an investment of $170.00 per kilowatt at the reference temperature of 700° F have been calculated by the use of Eqs. 1, 2, and 3. A yearly rate of depreciation, interest, insurance, and taxes of 15% has been assumed (*3, 7*). Fuel prices of 10, 20, and 30 cents per million BTU heating value were used. The results are plotted in Fig. 8.

The combined results in Fig. 8 show that there is little to be gained by increasing steam temperatures over 1,000° F if the fuel price is lower than 10 cents per million BTU. If the fuel is free, or if its cost is paid by funds not chargeable to the power station, it is most economical to build and operate a plant at about 600° F to 800° F.

A horizontal line drawn through, say, the 6-mill/kwh line shows that there is a possibility that a plant having as low a steam temperature as 350° F

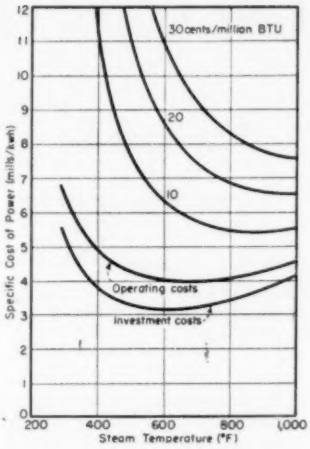

FIG. 8. Combined specific costs for steam-electric plants

may compete with a modern high-temperature plant, if the low-temperature plant does not have to pay its own fuel costs. But the machinery for such a low-temperature plant would be abnormally large and may be difficult to obtain from manufacturers geared to making conventional equipment.

Furthermore, one of the limiting factors in the possibility of increasing the total power supply in this country is the rate at which new turbo-generators can be built. In view of this, it would not be in the national interest to put a drain on manufacturing facilities by having large-size, low-efficiency equipment designed and built, if smaller, high-temperature equipment would serve the purpose as well or better.

* * *

This paper is based on studies conducted for the Atomic Energy Commission under Contract AT-11-1-GEN-8.

BIBLIOGRAPHY

1. Steam-electric plant construction cost and annual production expenses 1938-1947, Publication S-72 (Federal Power Commission, Washington, D. C.)
2. 1950 experiences at Port Washington station, *Combustion* **22,** No. 7, 39 (1951)
3. A. E. Knowlton, *Elec. World* **133,** No. 17, 99 (1950)
4. A. M. Selvey, P. H. Knowlton, *Trans. Am. Soc. Mech. Engrs.* **66,** 189 (1944)
5. P. H. Knowlton, R. W. Hartwell, *Trans. Am. Soc. Mech. Engrs.* **72,** 1017 (1950)
6. J. K. Salisbury, *Trans. Am. Soc. Mech. Engrs.* **64,** 231 (1942)
7. B. G. A. Skrotzki, W. A. Vopat, "Applied Energy Conversion," p. 350 (McGraw-Hill Book Co., Inc., New York, 1945)

CROSS SECTIONS

Possibilities of Fission-Product Cesium-137 For Telecurie Therapy

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Two isotopes are in current use for telecurie therapy, cobalt-60 (1.1, 1.3 Mev) and iridium-192 (0.6, 0.4, etc., Mev). Freundlich *et al.* (*1*) have developed a successful iridium-192 unit which, by comparison with cobalt-60, can be protected by a small casting of uranium. So long as the source radiation is harder than 300 kev, thus avoiding differential absorption in the different tissues, the easy shielding of sources may be an important factor in clinical use, and will be a great saving in size and cost of protective material.

The short half-life of Ir^{192} (70 days) necessitates having two sources, one being activated and the other being used. This means that for every such unit, a source will occupy a permanent position of high flux in the reactor.

Data on Cesium-137

As an alternative to Ir^{192}, the use of fission-product cesium-137 (*2*) is suggested. This isotope has a half-life of 33 years and decays either by a beta of 1.2 Mev (5%) to the ground state of Ba^{137} or alternatively by a beta of 0.52 Mev (95%) to metastable Ba^{137*} whence a single gamma of 0.66 Mev and half-life of 158 seconds takes it to stable Ba^{137}. The gamma may be internally converted from 8 to 12%.

The yield in fission is high (about 6%) since the mass number 137 occurs near the second peak of the fission humps. Cesium-137 follows the beta-decay chain of I^{137} to Xe^{137}, all of which are short-lived.

Medical Application

A source of concentrated Ce^{137} will give rather harder radiations than Ir^{192}. Iridium, however, contains a high proportion of soft gammas which may require filtering, whereas cesium gammas are monokinetic.

Concentration in a small volume seems feasible, although a special chemical technique would be needed, possibly using an ion-exchange resin.

Assuming a half-life of 33 years, carrier-free cesium atoms weigh about 12 mg/curie. It might be possible to concentrate 50 curies into a volume of several cubic centimeters; this is comparable in size with other types of telecurie sources.

The K factor from Mayneord's curves (*3*) for a quantum energy of 0.66 Mev gamma is about 3.9 r/hr/mc at 1 cm. Taking the 12% converted gammas from this gives a K of about 3.4 or 0.57 r/min/curie at 10 cm. A 50-curie source might yield 25 r/min at 10 cm.

Glendenin and Metcalf (*4*) give figures for attenuation of Ce^{137} by lead. Their half-thickness and tenth-thickness values are 7.5 gm/cm² and 25 gm/cm², respectively, corresponding to lead of 6.6 mm and 21.9 mm. Our own measurements on a small source show a simple exponential attenuation which confirms these figures. For such a source of 50 curies, the shield thickness need only be about 2¼ inches. This will give a conveniently compact unit.

* * *

Acknowledgement is made to the Director, A.E.R.E., for permission to publish this note.

BIBLIOGRAPHY

1. Freundlich, Haylittle, Quick, *Acta Radiol.* **34** (July, 1950)
2. K. Way *et al.*, Circular 499 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1950)
3. W. V. Mayneord, *Brit. J. Radiology*, Supplement 2 (1950)
4. C. Coryell, N. Sugarman, "Radiochemical Studies: The Fission Products," National Nuclear Energy Series IV-9, Book 2, p. 1063–1076 (McGraw-Hill Book Co., Inc., New York, 1951)

Constant Geometry For Dead-Time Determinations

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Radioactivity measurements using G-M counters frequently require that the resolving time or dead time of these detecting devices be determined. Ordinarily, determinations of dead time, τ, involve use of an expression similar to

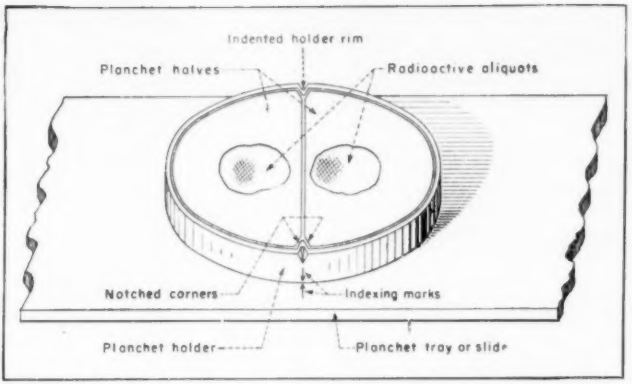
$$\tau = \frac{\Delta}{2n_1n_2} \cdot \frac{1}{8n_{12}2B_c} \cdot \frac{\Delta n_{12}}{n_1n_2}$$

where $\Delta = n_1 + n_2 - n_{12}$, and n_1, n_2, and n_{12} are the separate and combined counting rates of two sources, S_1 and S_2. For accurate results, special emphasis must be placed on maintaining constant geometry and juxtaposition of these sources during the counting-rate measurements.

The problem of reproducing geometry for the n_1, n_2, and n_{12} counting rates is usually troublesome. However, laboratories that routinely have available the common 1-inch-disk planchets plus a set-up such as a shielded "lead pig" or sample tray may conveniently make quick dead-time determinations without the need of additional special equipment.

The flat copper planchet* is cut along its diameter into two segments (a Di-Arco Notcher or similar cut-off tool is satisfactory for this operation). Two small notches are filed into each corner of each planchet half. These lock the segments in the planchet holder and facilitate later removal of the segments from the holder by means of a needle point. After being halved, the planchets are cleaned chemically in the usual manner and an aliquot of radioactive solution pipetted on each half. Two indentations are made in the rim of the planchet holder to match the notches in the planchet hhlves, as shown in the illustration.

Various commercial holders are available. The one used here is brass, 25.4 mm in diameter with a 0.7-mm rim within the periphery of which the planchet halves are positioned. The holder may be located with the aid of indexing marks on the slide or tray of a sample changer. The geometries of the two planchet segments are thus simply reproduced for the n_1, n_2, and n_{12} counts.



Position of planchet halves in holder. Geometry of each source is simply reproduced by means of the holder rim indentations and the indexing marks

Long-half-life sources such as Co^{60} will provide a permanent set-up which may be used over a long period. Isotopes with shorter half-lives such as I^{131} and P^{32} are useful in that a series of determinations, each separated by about a half-life, will indicate the dead-time dependence on count rates.

Apparatus for Administration of Colloidal Gold-198

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With the increasing clinical use of radioactive colloidal gold-198 in experimental medicine, it has become apparent that there is a need for administration apparatus that, while protecting the operator, will allow accurate measurement and easy handling without hazard.

Described here is an apparatus designed particularly for the intravenous, intrapleural, or intraperitoneal administration of colloidal Au^{198}. This apparatus is equally adaptable to similar operations with other radioisotopes. It has the following features:

1. It permits the accurate measurement and sterile transfer of calculated dosages from the shipping container to the administration equipment.

2. It involves the use of readily available and freely disposable tubing.

3. Since all active material is kept, except momentarily, in close fitting shields, and operations are conducted from a suitable distance, personnel exposure is at a minimum. For a dose of 125–150 mc, exposures of not over 4–10 mr are received by the operator.

4. Active material is, moreover, never more than a few inches above table height, an important factor in preventing spills and contamination.

Design Considerations

While the 0.96-Mev beta particles emitted by Au^{198} are mainly responsible for therapeutic effects, the isotope also emits 0.4-Mev gamma radiation that complicates handling. About 2 cm of lead are required to reduce the intensity of this gamma radiation to 1% of its unshielded value. With an unshielded therapeutic dose of 100 mc, the gamma radiation at 3 in. is in excess of 1,500 mr/hr. Shielding and remote operation are used to cut operator exposure.

Because AEC allocations call for definite limits on dosage, reasonably accurate measurements must be made of the volumes used. For this reason, use of prefilled containers is not to be countenanced. Moreover, since the volume given into a tumor should be based on the amount that the tissue will hold well, varying degrees of dilution must be possible.

We promptly discarded methods wherein the colloid was suspended in a shielded inverted flask on a stand and administered solely by gravity. The hazard of spillage is too great. Also, for direct tumor infiltration, considerable pressure is usually required.

To achieve the pressures required for direct tumor infiltration, most workers are using a lightly shielded syringe such as that made by A. S. Aloe and Co., St. Louis, Mo., and depend on speed to keep exposure at a reasonable level. We have found that such a syringe is too heavy.

Dr. M. Ter-Pogossian has recently constructed a heavily shielded syringe

*Supplied by Tracerlab Inc., Boston, Massachusetts.

which remains mounted on a table and is connected to the hypodermic needle with heavy-walled narrow-bore tubing.* The use of a screw arrangement permits the application of steady strong pressure.

Equipment and Its Operation

The equipment developed by us is in reality a modified composite of various suggestions. It provides for handling the colloid from the time it is removed from the shipping container to the time it is administered to the patient.

The radioactive gold colloid as supplied by our group has a specific activity of between 15 and 30 mc/cm.[3] It is contained in a hard glass, rubber-capped vial of appropriate size (5, 10, 20, or 30 cm³), packed in a 35–45 pound lead shield. To avoid contamination of this shield, the bottle should be removed, in a hot laboratory, and placed in a simple lead beaker having walls at least ¾-in. thick. The beaker should be just high enough that only the cap protrudes. For storage, another lead beaker can be inverted over the first one.

Removal from shipping bottle. Since the shipping bottle is frequently under some pressure, the initial puncture must be made by a short, sterile needle such as *A* in Fig. 1, that does not reach the liquid. If the needle is of wide bore, and preferably with a bell neck, it can also serve as an opening for removing portions of the colloid for use. A small pledget of cotton in the bell will avoid any spattering during release of the pressure.

For easy handling and insertion of the short needle, device *B* in Fig. 1, consisting of a piece of gum-rubber tubing over the end of a glass or metal rod with a tapered tip, can be fitted into the top of it. After insertion, simple rotation and retraction disengages the holder, leaving the needle open for the next step.

Removal and measurement can be accomplished with a shielded lead syringe such as that described previously, or with a remotely controlled pipette such as is manufactured by Tracerlab, Inc., Boston, Mass. As shown in Fig. 1, the pipette *C* is tipped with a thin needle *D*, long enough to reach to the bottom of the shipping bottle. The capacity of the needle can be determined in advance and applied as a correction to the pipette reading. The needle may be joined to the pipette by a ground joint or by a piece of pure gum-rubber tubing.

The shipping bottle is left in the lead beaker while the requisite volume of the colloid is quickly transferred in a sterile manner to container *G* of the infusion setup, shown in Fig. 1.

Infusion apparatus. Container *G* is simply a heavy-walled Pyrex receiver such as is used for vacuum distillations. At its top is a standard 19/38 standard-taper ground-glass joint that takes a standard ground-glass stopper. The container can be any size between 10 and 500 cm³, but to conserve shielding, 25–50 cm³ seems most advantageous. After the colloid is pipetted into container *G*, some sterile saline solution can be added if desired. Particularly if stoppered and further protected against spillage by a stainless-steel saucepan and covered by a lead cover, it may be safely transported on a cart or table to the administration room.

In the meantime, the portion *F*, consisting of the male part of the tapered stopper and appropriate outlet and inlet tubes, has been prepared and

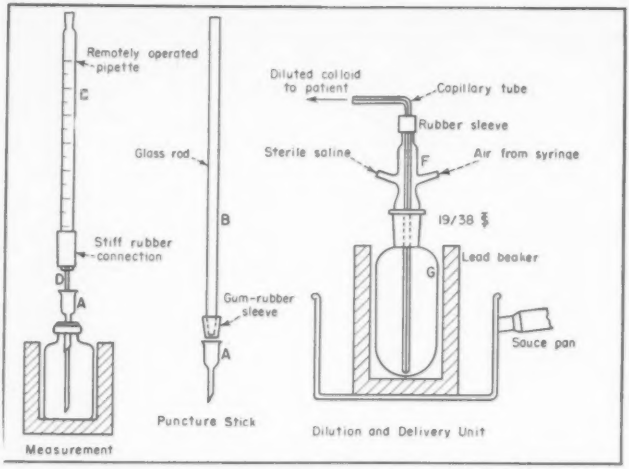

FIG. 1. Puncture stick for opening shipping container, remote-control pipette for measurement and transfer of colloid, and dilution and delivery unit used in infusion

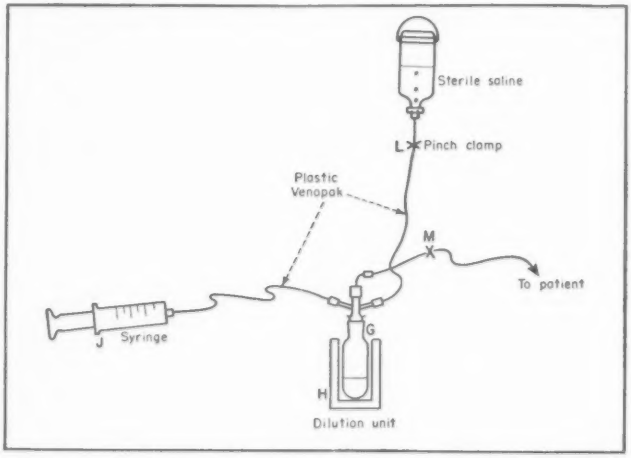

FIG. 2. Complete apparatus for dilution and delivery of colloidal gold to patient

* M. Ter-Pogossian, NUCLEONICS (to be published).

Berkeley INSTRUMENTS FOR SCINTILLATION COUNTING

Berkeley SCINTILLATION COUNTING HEAD Model 260

A directional gamma detector with ½" lead wall shielding and 3" lead plate with 13/16" aperture. Utilizes a thalium-activated sodium iodide crystal. Built-in cathode follower delivers output pulse to drive any scaler of .25 volt sensitivity. Plateau length is approximately 100 volts with Co^{60} gamma source; plateau slope is approximately 2% per 100 v.

Berkeley UTILITY SCALER Model 110

As a universal laboratory instrument for nuclear work, this instrument provides direct reading of results in digital form. Resolution to 5 microseconds, counting rate to 1,000 cps, and capacity to 999,999. Regulated high-voltage power supply of plug-in construction provides a continuously variable output from 0 to 2,500 volts. A simple reversal of parallel connections converts to a negative supply variable from 0 to −2,500 volts. Scaling factors of 100, 200 and 400 are provided with corresponding output signals available at standard accessory socket, to drive external register, metering circuit, computer, or other auxiliary device. Provision is also made for predetermined counts of 1,000, 2,000, 4,000, 10,000 or 20,000. Standard accessory socket permits use of predetermined timers, loudspeakers, other accessory devices.

Berkeley COUNT RATE COMPUTER

Model 1600 Converts random count information from any scaler into average counting rate. "Memory effect" of conventional count rate meters is eliminated: response is exceptionally rapid. Selector switch provides three ranges of 4, 40, or 400 cpm. Counting rate is indicated on the front panel meter.

Berkeley COUNT RATE RECORDER

A standard 1-milliampere recorder provides a permanent trace of counting rate.

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sterilized with connections in place. It is held with remote tongs and inserted firmly into G. It may be held in place by a rubber band if desired.

The complete infusion apparatus is shown in Fig. 2. The syringe J should be of at least the capacity of G. The saline container and delivery tubing used in our studies have been the standard Venopak unit made by Abbott Laboratories. The entire unit can be discarded after use.

Infusion operation. The Venopak bottle is mounted on the usual infusion stand. By opening screw clamp L and pulling back gently on the plunger of the syringe, the gold colloid is diluted to any desired volume. A slit in the back of shield H makes it possible to observe the volume of the liquid by using a mirror. By closing L, opening M, and pressing gently on the plunger of the syringe, the liquid can be forced over into the patient at any desired rate, stopping, of course, just before all liquid is transferred.

By closing M, opening L, and pulling back on the syringe plunger, fresh saline is drawn into G, washing down its walls. The injection step is then repeated. Since M and the tubing leading to the patient are of capillary, or at least very small, bore, and the colloid is already well diluted, the amount of activity outside the shield at any one time is quite negligible.

We have found that three such rinses result in reducing residual activity in G and F to so low a point that they may simply be held by short tongs during final decontamination with acid. They may be used again without waiting for decay to lessen the activity. The intermediate tubing and needle or trocar are also essentially free from activity, and if of the disposable type, are simply put along with wash liquids and sponges in a thinly shielded glass jar for decay and disposal.

The distance between G and the syringe can be as much as 3 or 4 feet, thus placing the operator far outside the range of the small amount of radiation passing through the lead shield. The clamps L and M are also outside the zone of radiation. Clamp L may well be of a remote-control type.

Refinements

Two refinements of this apparatus have proved valuable.

1. By having an unshielded duplicate, N, of G mounted beside it, all air bubbles may be removed from the tubing and actual infusion of nonradioactive saline started to check the patency of the tube entering the body cavity. Rapid change from N to G serves to initiate injection of the gold. This is obviously necessary if the equipment is used for intravenous administration in leukemia.

2. Having the syringe in its extended position and keeping L open results, in effect, in the transfer of the gold by hydrostatic pressure only, with gradual dilution taking place. At the end of the infusion, the air in the syringe is used to force all liquid out of G.

Carbon-14 Dating Used in Oceanography Study

Rate of movement and direction is a basic parameter in oceanographic work —determining water migration. Speculation over a number of years on the rate of turnover in ocean-bottom water has placed the figure all the way from tens of years to 10,000 or more.

Carbon-14 measurements carried out by Dr. J. L. Kulp at Lamont Geological Observatory (Columbia University, Palisades, N. Y.), gave an age of 1,600 years for water collected from a depth of 7,000 ft near the west side of the mid-Atlantic Ridge. An age of 1,750 years was found for a sample from a depth of 10,000 ft from east of the ridge. The accuracy of measurement is ± 150 years.*

One of the problems in this age determination was the collection of sufficient water for measurement. Approximately 300 gallons were taken on each of two expeditions with apparatus built by Dr. Kulp. Large cylindrical tanks, open at both ends, were sent down by cable to the ocean bottom. Each tank was fastened about 100 ft above the bottom-coring rig. Lids on both ends of each tank were hinged and, when shut by the triggering mechanism, were kept tightly closed by strong springs. The tanks were entirely watertight.

In processing the water collected, sulfuric acid is added to release the carbon dioxide contained in the water. Then carbon-dioxide-free nitrogen is bubbled through the water in the tank. This nitrogen stream carries the carbon dioxide from the water in the tank to a suitable absorbent (a pound of ascarite). The CO_2-loaded ascarite is then sealed and brought back to the laboratory.

In the laboratory, hydrochloric acid is added to the absorbent to release the CO_2, which is then purified and reduced to pure carbon by the use of hot magnesium metal.

To make the age measurement, the purified carbon is coated on the inside of a screen-wall Geiger counter placed inside a 12-ton iron shield that, in conjunction with a battery of anticoincidence counters, reduces the effect of cosmic radiation on the measurement.

If the sample is counted for four days, the accuracy of the age measurement for fairly recent samples is ± 100 years. An ocean-water sample obtained from the surface of the water was used as a control; it gave a result identical with that obtained with living marine organisms obtained from many parts of the world.

* These measurements and the techniques described here were reported in "Natural Radiocarbon Measurements," a paper presented at the American Association for the Advancement of Science, Philadelphia, Pa., Dec. 28, 1951.

TECHNICAL BRIEFS

• **Silicone oil** should be used carefully in vacuum diffusion pumps. Vapor from the oil can lower the secondary emission coefficient, according to A. Lempicki and A. B. McFarlane in *Nature* **167,** 813 (1951).

• **Accelerator beam** intensity measurements with "r" meters are affected by the surroundings at high energies. At Case Institute of Technology, it was found that fluorescent radiation affected readings even though the meters were placed between the source and a block of lead.

• **Proper joint fit-up** is one of the most important factors in obtaining a strong, leak-tight joint when welding thin-walled tubing with the inert arc process. R. S. Zeno and H. L. Leslie, in AECU-1546, recommend that a press fit, with the joint cleaned with a vapor-phase degreasing agent, be used. For a more stable arc, zirconium oxide or thoriated tungsten electrodes should be used, and argon is preferred to helium for welding type-347 stainless steel.

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BOOKS

Automatic Feedback Control, by William R. Ahrendt and John F. Taplin, McGraw-Hill Book Co., Inc., New York, 1951, xiv + 412 pages, $7.50.

The literature on feedback, its implications and its applications, has grown rapidly in the postwar years. The market is by no means saturated, however, and the "official" appearance of the present volume is welcomed. (The first six chapters had been informally published by the authors in 1946.) This book is characterized by a good general mathematical treatment, followed by detailed attention to several fields of application.

The authors, evidently writing from a considerable store of practical experience, choose as principal target the field of industrial process control, with some attention to servomechanisms (defined here as position controls). Headings for the last five chapters (9 to 13) are: *Servomechanisms; Pneumatically Operated Controllers; Temperature Regulation; Speed Governing;* and *Pressure, Flow, and Liquid Level.* These chapters, combining practical details with relevant theory, are the most distinctive portion of the book.

The first seven chapters give the general theory of linear feedback systems, based entirely upon the Laplace transform. Making liberal use of block diagrams and graphs, as well as formulas, the authors cover the wide scope of this theory with reasonable thoroughness.

Chapter 8 is devoted to nonlinearity and discontinuity, and, perhaps as well as can be done in 41 pages, gives a useful introduction to these important topics. In the last fifty pages of the book, a list of problems is given, restricted however to the subject matter of Chapters 1 to 6.

Mathematical equipment expected of the reader is presumably that required for study and use of Laplace transforms (specifically, ability to think clearly about ordinary differential equations and their solutions). There is a marked tendency to minimize mention of differential equations as such, and to speak instead in terms of transforms and transfer functions. This can be dangerous, especially for the uninitiated or unwary. For this and other reasons, the theoretical treatment cannot be recommended as a straight dose for the beginner, unless carefully administered by an experienced teacher or supplemented with collateral study.

The volume certainly deserves a critical reading by all who take a real interest in automatic control and in servomechanisms.

As a textbook, it will be of particular value in chemical and mechanical engineering curricula.

Any book that cuts across so many technological fields is burdened with the problem of choice of symbols and terminology. The present authors have made a commendable effort to use symbolism jointly recommended by the ASME and the AIEE, but this is far from a complete remedy, and the problem needs continuing effort.

In regard to terminology, matters are even worse. Though on the whole the present work shows careful and judicious choice of concepts and terms, there is one clear example of the wrong way. This is the confusion introduced (on p. 16, p. 152, and in Chapter 8) into the distinction between linear and nonlinear systems. In failing to emphasize the simple mathematical definition of linearity and in promoting word usage directly in violation of this definition, the authors foster another of those painful divergences between mathematics and engineering which our age can no longer afford.

Modern man is exceedingly busy being scientific and technical about many things—about almost everything, in fact, except his science and technology. Until the engineering sciences are better organized, coordinated, and understood as a whole, our present hit-or-miss communication of engineering knowledge must continue. Widespread study and appreciation of "horizontal" topics such as feedback should hasten the new day. Nucleonics, especially tracer techniques and reactors, is a field of similar horizontal, unifying quality.

—John D. Trimmer
Dept. of Physics, University of Tennessee Knoxville, Tennessee

Atomic Energy in War and Peace, by Capt. Burr W. Leyson, E. P. Dutton & Co., Inc., New York, 1951, 217 pages, $3.75.

This is another popular treatment of the subject with more pictures of the effects of the Hiroshima and Bikini bombs and odd statements on atomic energy and its uses that the serious student will not want to take as the last word on the matter. For instance, cobalt-60 is called a "radioactive isotope of cobalt 58.9," and the reader is referred to the back of the volume to consult a bibliography that is not to be found—at least not in the review copy received by this office.

Fluorine and Its Compounds, by R. N. Haszeldine and A. G. Sharpe, John Wiley & Sons, Inc., New York (or Methuen & Co., Ltd., London), 1951, 153 pages, $1.75.

With publication of this monograph, Wiley adds to its Methuen series of biochemical, biological, and physical monographs the first in a new series of these pocket-size, cloth-bound books, to be known as Methuen's Monographs on Chemical Subjects. "Fluorine and Its Compounds" reviews the modern inorganic and organic chemistry of the element. The relation between structure and properties of inorganic fluorides and the influence of fluorine on the properties and reactivity of organic compounds is explained.

BOOKS RECEIVED

Energy Sources—The Wealth of the World, by Eugene Ayres and Charles A. Scarlott, McGraw-Hill Book Co., Inc., New York, 1952, vii + 344 pages, $5. (*To be reviewed.*)

The Measurement of Radio Isotopes, by Denis Taylor, John Wiley & Sons, Inc., New York (or Methuen & Co., Ltd., London), 1951, viii + 118 pages and 40 diagrams, $1.50. A monograph in the Methuen series on physical subjects. (*To be reviewed.*)

Principles of Quantum Mechanics (Nonrelativistic Wave Mechanics with Illustrative Applications), by William V. Houston, McGraw-Hill Book Co., Inc., New York, 1951, vii + 288 pages, $6. A volume in the International

THE PERKIN-ELMER

INSTRUMENT DIGEST

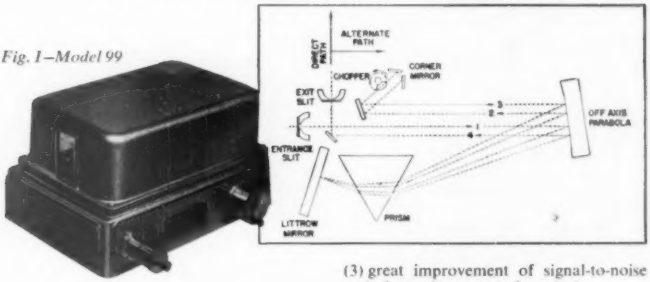
A condensation of some of the articles appearing in the Fall issue of THE PERKIN-ELMER *INSTRUMENT NEWS*, a quarterly publication of The Perkin-Elmer Corporation, manufacturers of scientific instruments—Infrared Spectrometers, Tiselius Electrophoresis Apparatus, Universal Monochromator, Flame Photometers, Continuous Infrared Analyzer, Low-Level Amplifiers—as well as Astronomical Equipment, Replica Gratings, Thermocouples, Photographic Lenses, Crystal Optics, and Special Instruments for the Government. **For further information, write The Perkin-Elmer Corp., Norwalk, Conn.**

Norwalk, Conn. | January, 1952 | Vol. 3, No. 2

New Optical Principle Improves Instruments' Performance

Model 99 Monochromator and Model 112 Infrared Spectrometer Have Double Pass Feature

Fig. 1—Model 99



A new optical "double pass" principle involving the passage of radiation four times through the prism of a Littrow-type monochromator instead of twice, results in double monochromator performance with single monochromator cost and simplicity.

New Instruments—This principle has been applied with great advantage to two new Perkin-Elmer instruments. In the new Model 99 Double Pass Monochromator, monochromatic radiation of high spectral purity is achieved by maximum utilization of existing optical components with minimum mechanical complication. The Model 99 Monochromator has also been incorporated with the source unit and recording system of the Perkin-Elmer Model 12-C Infrared Spectrometer to form the Model 112 Infrared Spectrometer. The advantages of the double pass feature here are:
(1) virtual absence of scattered radiation;
(2) twice the spectral resolution than could be achieved with a single optical system of the same dimensions;
(3) great improvement of signal-to-noise ratio for a given spectral resolution.

Because of the double passage of radiation in the new monochromator, dispersion is doubled, and scattered radiation is reduced to a negligible amount throughout the ultraviolet, visible and infrared range. Energy per spectral slit width is doubled, times the efficiency factor of the instrument (.75 for infrared).

The Model 99 is essentially the Perkin-Elmer Model 83 Universal Monochromator plus the double pass feature.

Optical Path—Light entering the entrance slits is collimated by the off-axis paraboloid on the prism (Fig. 1). After one refraction the beam is reflected by the Littrow mirror for a second refraction by the prism. The returning beam is brought to a focus by the paraboloid between the two halves of the corner mirror. The corner mirror sends the beam back through the system slightly displaced so that after a second traversal through the paraboloid, prism and Littrow portion, the beam is brought to a focus on the exit slit. A radiation chopper is inserted after the corner mirror so that signals produced in the detector by first and second pass radiation may be separated.

Performance data of the Model 99:

Resolution:
Better than 0.5 Å at 2500 Å (quartz prism)
Better than 1 Å at 5000 Å (glass prism)
Better than 2 cm^{-1} at 1000 cm^{-1} (NaCl prism)
Scattered Radiation:
Less than 0.1% throughout the range
Range:
From 2000 Å to 40 microns (with suitable prisms)

New Infrared Spectrometer—The advantages of the double pass monochromator for infrared spectroscopy are of considerable importance. For qualitative work the improved resolution means greater discriminatory powers for the spectrometer (Fig. 2). Thus more nearly similar materials may be better detected by infrared methods, or structural analyses may be carried further.

For quantitative measurements, improved resolution is also valuable. From a consideration of Beer's Law, the more nearly monochromatic the spectral band used for measurement, the more closely will a plot of absorbance vs. concentration approach a straight line. Of more importance for accurate concentration determination, is the practically complete absence of false radiation.

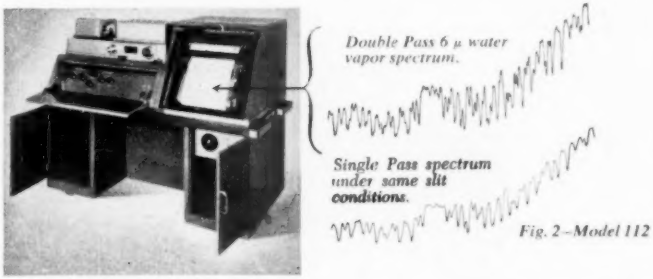


Fig. 2—Model 112

All of the other features of the Perkin-Elmer Model 12-C Infrared Spectrometer are retained in the Model 112. Accessories for Models 12-C and 21 may be used with Model 112.

The double pass feature may be added to any Perkin-Elmer Model 83 Monochromator or Model 12 Spectrometer.

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Featured in the Winter issue are:
DOUBLE PASS PRINCIPLE
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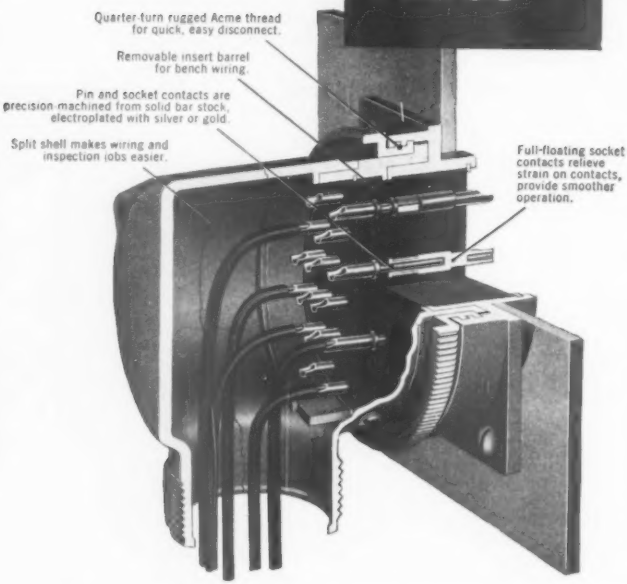
Here's why those in the know –demand

CANNON PLUGS


Quarter-turn rugged Acme thread for quick, easy disconnect.
Removable insert barrel for bench wiring.
Pin and socket contacts are precision-machined from solid bar stock, electroplated with silver or gold.
Split shell makes wiring and inspection jobs easier.
Full-floating socket contacts relieve strain on contacts, provide smoother operation.

Recognition of Cannon's 36 years of sound engineering and fine, uncompromising construction has built the demand for Cannon Plugs. Here we take an inside look at the lightweight Type "K" 90° connector, forerunner of the Army-Navy Series. More features of the "K" were incorporated into the "AN" design than any other connector.

Constantly improved over the years, Type "K" is now used for numerous applications such as aircraft, radio, television, sound, phone recorders, motion pictures, geophysical research and widely used throughout the electro-mechanical and electronic instrument fields.

The design and construction details in the Cannon "K" Series are typical of the care Cannon takes in producing more than 18,000 precision, multi-contact connectors to serve the exacting needs of industry.

We will gladly send you engineering bulletins describing each of the many basic types of Cannon Plugs if you will briefly describe your applications.

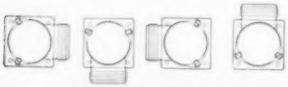


Diagram at left shows how the four positions of cable entry on the large 90° "K" endbell make the wiring job easier. Smaller Type "K" connectors have three positions.

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Series in Pure and Applied Physics. (*To be reviewed.*)

Applied Atomic Energy, by K. Fearnside, E. W. Jones, and E. N. Shaw, Temple Press, Ltd., London, 1951, vii + 156 pages, 8/6d. A book in the Technical Trends Series. (*To be reviewed.*)

OTHER LITERATURE

Supplement 2 to "Nuclear Data" (National Bureau of Standards Circular 499). Issued November 26, 1951, this is the July, 1950, to January, 1951, supplement to the collection of experimental values of half-lives, radiation energies, relative isotopic abundances, nuclear moments, and cross sections, compiled by the NBS Nuclear Data Group (Katharine Way, Gladys Fuller, Marion Wood, Karin Thew, and Alice Jurgens). It contains a new class of information not included in Supplement 1, that is, a year's list of fission and spalation papers. *NBS Circular 499 is available from the Superintendent of Documents, GPO, Washington 25, D. C., $4.25; this price includes three supplements (the second of which is described above) that include data reported during the three six-month periods ending July 1, 1950, January 1, 1951, and July 1, 1951. Supplements are mailed automatically to purchasers of the circular.*

The Role of Engineering in Nuclear Energy Development (TID-5031). Pamphlet containing the proceedings of the 1951 Oak Ridge Summer Symposium held at Oak Ridge, Tenn., Aug.–Sept., 1951 (509 pages). *Office of Technical Services, Dept. of Commerce, Washington 25, D. C., $1.40.*

Recommendations of the International Commission on Radiological Protection and of the International Commission on Radiological Units, 1950 (National Bureau of Standards Handbook 47). Pamphlet containing 29 pages of recommendations adopted at the Sixth International Congreee of Radiology, together with best available data on permissible amounts of radioisotopes in the body and specifications of conditions for radiological treatment. *GPO, Washington 25, D. C., $0.15.*

Control and Removal of Radioactive Contamination in Laboratories (National Bureau of Standards Handbook 48). This 24-page pamphlet was prepared by the Subcommittee on Waste

Disposal and Decontamination of the National Committee on Radiation Protection. It provides the best available information for laboratory personnel on how to deal with and prevent contamination in the lab and on their persons. *GPO, Washington 25, D. C., $0.15.*

List of 30 Patents Released for Public Use by the AEC (Vol. I, No. 15, December 18, 1951). *Issued by Chief, Patent Branch, Office of the General Council, U. S. Atomic Energy Commission, Washington 25, D. C.*

Planning and Organizing for Radiological Defense and Civil Defense. An excellent manual for CD planners who seek to interest professional personnel in radiological defense programs. Suggestions for establishing courses, and outlines for such courses, are contained in a companion manual entitled **Training Plan Courses in Medical Aspects of Atomic Warfare, Medical Aspects of Radiological Defense, and Radiological Defense for Monitors.** *Available without cost from the Council on National Emergency Medical Services, American Medical Association, 535 N. Dearborn St.,* Chicago *10, Ill.*

Monte Carlo Method, edited by A. S. Householder (National Bureau of Standards Applied Mathematics Series 12). A 42-page publication containing selected papers read at the recent Symposium on the Monte Carlo Method held at the University of California, Los Angeles. It comprises, in effect, a study on the work done in the United States with this interesting combination of sampling theory and numerical analysis. *GPO, Washington 25, D. C., $0.30.*

Three Charts for X-ray Diffraction Studies, published by Illinois Institute of Technology. These charts offer a rapid, convenient method of indexing X-ray diffraction patterns to determine crystal structure for lattice parameter calculation. Based on charts originated by W. P. Davey and A. W. Hull, which appear in the book "Study of Crystal Structure and Its Applications," they are tetragonal and hexagonal system charts plotted up to 6th order reflections with axial ratios ranging from 0 to 2.6. The cubic lattice chart has been plotted up to 12th order reflections. *Metals Research Department, Armour Research Foundation, Illinois Institute of Technology, 35 W. 33d St., Chicago 16, Ill., $5.*

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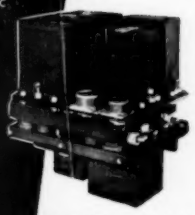

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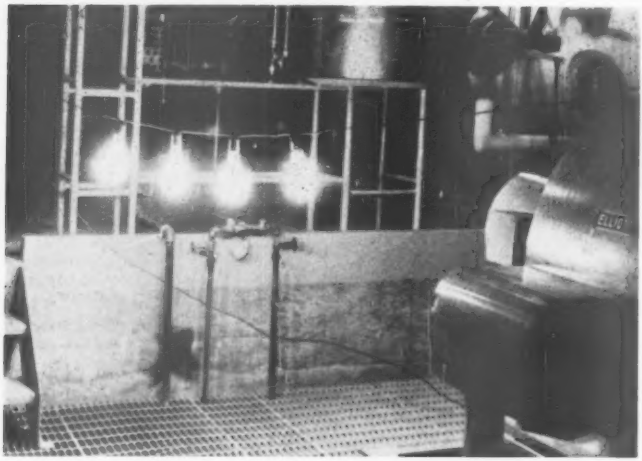
NUCLEONIC EVENTS



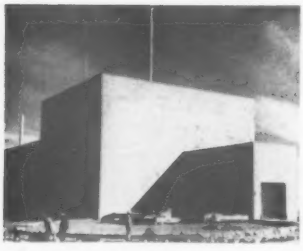
The electric light bulbs in this picture show the first known use of electric power from nuclear energy. They were lighted by electricity from the generator at the right which, in turn, was operated on heat from the Experimental Breeder Reactor—Arco, Idaho, December 20, 1951

Experimental Breeder Reactor Used to Produce World's First Nuclear-Generated Electric Power

Electric power was produced by means of a nuclear reactor for the first time in the world six weeks ago, according to an announcement from the Atomic Energy Commission. In a trial run on the experimental breeder reactor at Arco, Idaho, more than 100 kilowatts were generated and used to operate the pumps and other reactor equipment and to provide light and electrical facilities for the building that houses it. See pictures on this page.

The heat energy generated was removed from the reactor by a liquid metal at a temperature high enough to generate steam to drive a turbine.

No economic significance should be attached to the production of power from this reactor at this time, according to Dr. Walter H. Zinn, director of Argonne National Laboratory where the pile was designed. The principal function of the reactor is "breeding," the long-range goal of converting non-fissionable material into fissionable material more rapidly than nuclear fuel is consumed.



Building housing the Experimental Breeder Reactor

The power-generation phase is incidental, states the AEC, but is being carried out to secure experimental information on the handling of liquid metals at high temperatures under radioactive conditions and on the extraction of heat from a reactor in a useful manner.

The reactor is now presumably operating at full power rating since, in its "Tenth Semiannual Report to Congress," the AEC said that experimental amounts of power would be produced only when that point was reached.

It may be some time before it is known whether the "breeding" operation is successful. The reactor, which is the first major one designed to operate with "fast" neutrons, is using enriched uranium as fuel and a blanket of natural uranium around the core as the "fertile" material in which breeding may take place. The rate of fuel burn-up will be compared with the rate at which the nonfissionable uranium-238 in the natural uranium is converted into new fuel, fissionable plutonium.

The reactor itself and its principal components were erected at the Idaho Testing Station by the Argonne National Laboratory, with H. V. Lichtenberger as the project engineer. The Austin Company, Cleveland, designed the building and some of the reactor system. Construction at the site was by the Bechtal Corporation, San Francisco, under the supervision of the AEC's Idaho Operations Office headed by L. E. Johnston.

Total construction cost was about $2,700,000. Approximately $2,500,000 was spent by the laboratory over a four-year period for research and engineering development.

Included in the construction cost are water supply, feeder power line, access road, excavation, fabrication of structural steel, and yard development, in addition to construction of the reactor building, cooling system, power take-off apparatus and controls. Also a part of this figure is the architect-engineering work and fabrication of reactor components.

Como Selected as Site of European Nuclear Center

Representatives of delegates from twelve nations attending a recent conference in Paris to discuss plans to set up a central nuclear physics laboratory in Europe have selected the Italian city of Como as the site for the center.

To be supported by various Western European nations, the work planned for the center will be nonsecret, basic research. Plans include the erection of a nuclear reactor and the establish-

ment of an institute for advanced nuclear study at the center. Work to complete the center will probably take about six years.

Great Britain, moving toward the advancement of European cooperation in research, announced at the conference that she is willing to make available to the nations represented the 400-Mev synchrocyclotron now nearing completion at Liverpool University.

Kellogg Gets $75-Million Contract for Paducah Piping

The M. W. Kellogg Company, New York, announced last month that it had been awarded a $75,000,000 contract for the field-fabrication and erection of the process and auxiliary piping and related equipment in the two major gaseous-diffusion units now well underway at the Atomic Energy Commission's plant at Paducah, Ky.

The processing sections of the plant, considered the ultimate in complexity, will require 50,000,000 pounds of special piping designed for resistance to corrosion as well as low-temperature operation. The Paducah units are similar to the K-25 installation at Oak Ridge, which is set up for separating U^{235} from uranium hexafluoride and which Kellogg, through a specially formed subsidiary, engineered during World War II.

Uranium Feed Materials Processes Undergo Survey

The Atomic Energy Commission has authorized an intensive survey of its uranium feed materials production processes and has announced that the Catalytic Construction Company of Philadelphia will conduct the work, with the participation of the technical staff of the Houdry Process Corporation. According to a statement by Wilbur E. Kelley, manager of the AEC's New York Operations Office, the survey, which must be completed in six months, "is part of a comprehensive program designed to improve our existing processes wherever possible and to develop new ones."

The initial phase of the survey will consist of an economic and engineering study of all uranium feed materials processes, covering those still under construction as well as those already in operation. In addition, it will include an investigation of related research and development work through the AEC and a review of all published data on uranium technology.

The over-all survey will attempt to determine in what areas of the uranium production chain research and development work should be undertaken, how existing processes might be improved, and what pilot-plant operations should be initiated to test out new processes.

Whitney Weinrich, chief process engineer for Catalytic at the AEC's Feed Materials Production Center now under construction near Cincinnati, Ohio, will direct the survey project.

The design and engineering contract for the new Center, originally awarded to Catalytic in November, 1950, has been expanded to include process development, design, and procurement for two additional production units.

South Australia Plans Atomic-Energy Plant

The government of South Australia is expected to take its first steps soon toward establishing an atomic energy plant. Government officials are presently awaiting word from Director of Mines, S. B. Dickinson, on the results of his visit to the United States and England to obtain data on the latest atomic-energy developments.

The government hopes that the contemplated plant will be ready for operation within ten years. One of the first steps will be the installation of a sink float mill purchased in the United States and expected in South Australia early this year. The mill will be used for separating uranium ore from waste material.

Blaw-Knox to Do Atomic-Energy Research

Stating that "special attention will be given to development of industrial applications of atomic energy," E. W. Forker, head of the Chemical Plants Division of Blaw-Knox Company, Pittsburgh, Pa., last month announced the organization of a Research and Development Department within the division.

Among the functions of the new department will be the study and evaluation of new processes. Dr. H. B. Coats has been appointed director of the department.

Cobalt Source for Cancer Ready for Shipment

Last month the Isotopes Division of the Atomic Energy Commission reported that the largest radioactive source ever produced in the United States for treatment of cancer in humans was ready for shipment from Oak Ridge. A 1,000-curie cobalt-60 source, it is being sent to the Los Angeles Tumor Institute, Los Angeles, Calif., which purchased the source for less than $10,000.

The metal cobalt-60 is in the form of six rods, each 3.2 cm long and 1 cm in diameter. The total weighs less than $\frac{1}{2}$ lb, but because of the heavy shielding necessary for protection against its intense radioactivity, it is being shipped in a special lead container weighing 3,000 lb. The container was designed by the Tumor Institute.

The cobalt was irradiated in the reactor at the Oak Ridge National Laboratory, which is operated for the AEC by the Carbide and Carbon Chemicals Co.

A similar but less powerful cobalt-60 source was procured through the AEC Isotopes Division last year by the Chicago Tumor Institute. Rated at 340 curies, this source is being tested and probably will be used in Chicago later this year for treatment of cancer.

President Nominates Zuckert to AEC

Eugene M. Zuckert, Assistant Secretary of the Air Force since 1947, has been nominated by President Truman for membership on the Atomic Energy Commission. The nomination, awaiting confirmation by the Senate, was made to fill the AEC vacancy created in December by the resignation of Sumner T. Pike. The term Mr. Zuckert has been named for expires on June 30, 1954.

IN BRIEF

• *The principal results of recent talks between Gordon Dean, chairman of the U. S. Atomic Energy Commission and Lord Cherwell, Winston Churchill's adviser on atomic energy, during his visit with the Prime Minister to this country, was a proposed meeting of a group of British and American scientists*

to discuss exchange of specific information on the technical aspects of atomic-energy development. According to a law recently passed by Congress, such exchange of information can be made only if it is "substantially beneficial to the United States."

• The National Science Foundation received 2,800 applications for its 400 graduate fellowships for the 1952–53 academic year. Final awards will probably be announced in April. According to its recent report to Congress, which set up the Foundation in 1950, granting of these fellowships will be the NSF's first order of business so as to produce the most immediate effects on the supply of scientific man power.

• *The glass industry did a $10,000 business in 1949–50 in shielding glass for viewing radioactivity work—$100,000 in 1950–51. It is predicted the 1951–52 figure will be $1,000,000.*

• A 250-kv particle accelerator is being constructed for the Los Alamos Scientific Laboratory by the American Instrument Company, Inc., of Silver Spring, Md. Construction and installation costs will amount to $60,000.

• *Representative of some of the advanced thinking on the part of public health officials is the recent formation of an Advisory Committee on Radioisotopes by the Chicago, Illinois, Board of Health.*

• Speaking in Utrecht, the Netherlands, Dutch atomic scientist J. M. W. Milatz recently made public plans for construction of a ship of 5,000 tons to be operated by nuclear power. Discussions on the design of a reactor for the vessel have been carried out with Odd Dahl, designer of the heavy-water reactor recently put into operation at Kjeller, Norway.

• *A shortage of British scientists trained in nuclear physics and atomic research is hampering the extensive nuclear research program which Marcus Oliphant has planned for the Australian National University in Canberra. Dr. Oliphant is director of the university's Research School of Physical Science.*

• The last (K-31) of the gaseous diffusions plants to be built at Oak Ridge has been completed. Carbide & Carbon Chemicals Co. will operate it.

270 Radioisotopes Shipped from Brookhaven in First Year of Operation

The Brookhaven National Laboratory last month released figures to show that the BNL reactor supplied 270 radioisotopes for shipment to 26 different research organizations during 1951, its first full year of reactor operation. These figures do not include the several hundred isotopes used by staff scientists of the laboratory.

The institutions that received the greatest number of shipments from Brookhaven in 1951 were: Harvard University, Cambridge, Mass., 60; Columbia University, New York, 44; Veterans Administration Hospital, New York, 44; Massachusetts General Hospital, Boston, 29; New York University College of Medicine, New York, 29; Massachusetts Institute of Technology, Cambridge, 13; and Sloane-Kettering Institute for Cancer Research, New York, 12.

Among the radioisotopes supplied were 100 shipments of sodium-24 and 91 shipments of potassium-42, with half-lives of 15 and 12.4 hours, respectively.

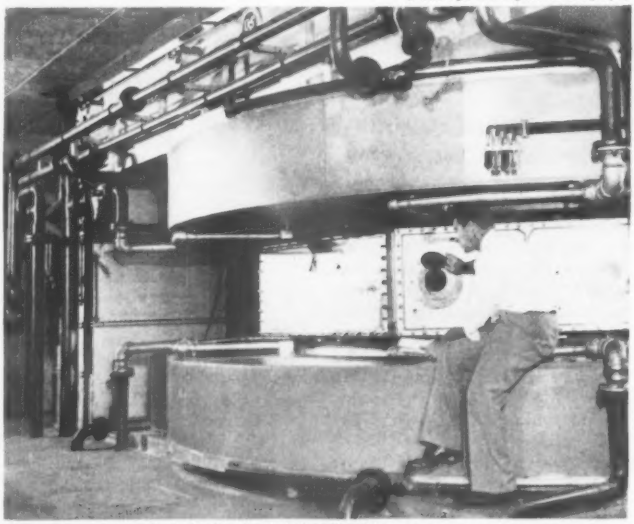
University of California Medical Center Opens New Radioactivity Laboratory

A novel radioactivity center has been installed in the first unit to be completed as part of the new $21,080,000 University of California Medical Center in San Francisco. The radioactivity laboratory, set up in a small four-story unit of the Medical Sciences Building, will serve the needs of the whole medical center for radioisotopes in research, diagnosis, and treatment.

The only one of its kind in the West, the radioactivity center will be directed by Kenneth G. Scott, assistant professor of experimental radiology. Its operation is supported by university funds, and supervision is exercised by a committee composed of Dean Troy Daniels, School of Pharmacy; Dean Willard C. Fleming, College of Dentistry; and Dean Francis Smyth, School of Medicine.

Dean Smyth, speaking for the committee, said that the radioactivity center offers the individual investigator

(Photo by Pittsburgh Sun-Telegraph)



CARNEGIE TECH ACCELERATOR STARTS OPERATION. Under construction since March, 1948, the $2,500,000 synchrocyclotron at Carnegie Institute of Technology in Pittsburgh, Pa., was recently declared "open for business." Mesons have already been produced, according to Edward C. Creutz, director of Carnegie's Nuclear Research Center, and protons of 400 Mev have been observed. Martyn H. Foss designed the accelerator's magnet, which has 191.65-inch pole tips. Funds for the machine were made available by the Buhl Foundation, the Office of Naval Research, and the Atomic Energy Commission

the space, some $60,000 in specialized equipment, and the advice and aid of a staff experienced in the use of radioisotopes.

NUCLEAR NEWSMAKERS

Edward R. Trapnell has been granted a leave of absence as associate director of the AEC's Division of Information Services to serve as head of a nine-man subcommittee of the Interdepartmental Committee on Internal Security, the subcommittee charged with coordinating President Truman's program for guarding security information and seeing that security classifications are not used on nonsecurity matters.

Frank H. Spedding, director of the Institute for Atomic Research at Iowa State College, has been named to receive the 1952 William H. Nichols Medal of the American Chemical Society's New York Section. The award, one of the highest in American chemistry, will be made to Dr. Spedding at an ACS dinner in New York on March 14.

Enrico Fermi, of the Institute of Nuclear Studies, University of Chicago, last month was awarded an honorary degree of doctor of science by the University of Rochester.

Ernest O. Lawrence, designer of the cyclotron and University of California physicist, recently received the $1,000 William Proctor Prize for Scientific Achievement awarded by the Scientific Research Society of America.

Edward C. Lloyd has been appointed assistant chief of the Office of Basic Instrumentation of the National Bureau of Standards. He formerly served as principal marine engineer with the Navy Department's Bureau of Ships.

Eric T. Clarke, Marvin G. Schorr, and **Arthur J. Stevens,** all formerly associated with Tracerlab, Inc., have organized a new company, Technical Operations, Inc., located in Boston, Mass. The company will serve the nucleonics field and engage in operations research. **Frederick C. Henriques,** formerly technical director of Tracerlab, has been appointed as the company's director of government contract research.

W. R. Engstrom, vice president of The Austin Company since 1943 and director of the company's projects for the Atomic Energy Commission since

SOLID STATE PHYSICS

Cryogenic

- **Nuclear resonance experiments**
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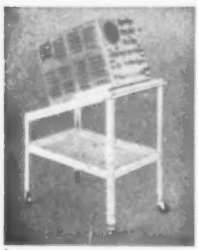

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1948, is returning to Seattle as vice president and manager of the company's Pacific Northwest District. **Edmund J. Goodhart,** who served as Austin's general superintendent under Mr. Engstrom during construction of the new AEC facility at Rocky Flats, Colo., has been given additional responsibilities there as assistant project manager. Mr. Engstrom will continue to supervise AEC work for the company.

Wilfred Mann recently was named to head the radioactivity section of the Atomic and Radiation Physics Division of the National Bureau of Standards.

Guy W. Thaxton has joined the staff of the Atomic Energy Commission's Division of Construction and Supply. As power engineer, he will be responsible for staff coordination of all matters pertaining to power supply for AEC operations. He comes to AEC from the Defense Electric Power Administration.

Lauriston C. Marshall, professor of electrical engineering at the University of California and head of the university's Microwave Laboratory, has accepted appointment as director of the Link-Belt Company's new Physical Testing and Research Laboratory at Indianapolis. Dr. Marshall will take over his new duties with Link-Belt as soon as he can be released from his present commitments, which include nuclear research projects being carried out at the University of California's Radiation Laboratory.

Keith H. Johnson has been appointed assistant to the president of Radiation Counter Laboratories, Inc., Skokie, Ill. He was formerly supervisor of the company's counter department.

D. L. Collins, technical director of the Victoreen Instrument Company, is taking on additional duties with the company and has been appointed head of the components division. **F. W. Reuter** has been named chief engineer of the division.

Farrington Daniels, professor of chemistry at the University of Wisconsin and member of the AEC's Advisory Committee on Chemistry, has been chosen president-elect of the American Chemical Society. Dr. Daniels, in 1945–46, directed the work of the Metallurgical Laboratory at the University of Chicago, where much of the research for the Manhattan Project

was conducted, and from 1946–48 served as chairman of the board of governors of Argonne National Laboratory. He will head the ACS in 1953.

George B. Pegram, vice president of Columbia University and one of this country's pioneers in the development of atomic energy, has been elected president of the New York Academy of Sciences. Columbia's dean of engineering, **John R. Dunning,** was elected to a vice presidency in the Academy.

Allen V. Astin has been appointed acting director of the National Bureau of Standards to succeed **E. U. Condon** who resigned the post early last year. Dr. Astin, who was associated with the wartime development of the proximity fuse, has been serving as associate director of NBS.

NECROLOGY

Malcolm M. Haring (January 1, 1952). Director of the Mound Laboratory of the Monsanto Chemical Company, Dr. Haring died at the age of 57 in Dayton, Ohio. He joined Monsanto in 1944 on leave as research chemist from the University of Maryland where he had been professor of physical chemistry since 1923. Consultant to the Atomic Energy Commission, he held degrees from Franklin and Marshall College, Princeton University and Columbia University. From 1936–1948, he served as associate editor of the *Journal of Chemical Education.* He was selected in 1948 to direct work at the Mound Laboratory, center of Monsanto's atomic research located in Miamisburg, Ohio.

MEETINGS

Institute of Radio Engineers, National Convention—Waldorf-Astoria Hotel, New York, Mar. 3–6

Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy—William Penn Hotel, Pittsburgh, Pa., Mar. 5–7

National Association of Corrosion Engineers, Eighth Annual Conference and Exhibition—Galvez Hotel, Galveston, Tex., Mar. 10–12

American Physical Society—Columbus, Ohio, Mar. 20–22

American Society of Mechanical Engineers—University of Washington, Seattle, Wash., Mar. 24–26

American Chemical Society, 121st National Meeting—Buffalo, N. Y., Mar. 23–27; Milwaukee, Wis., Mar. 30–Apr. 3

Symposium on Radiation Chemistry, sponsored by the Faraday Society—University at Leeds, England, Apr. 8–10

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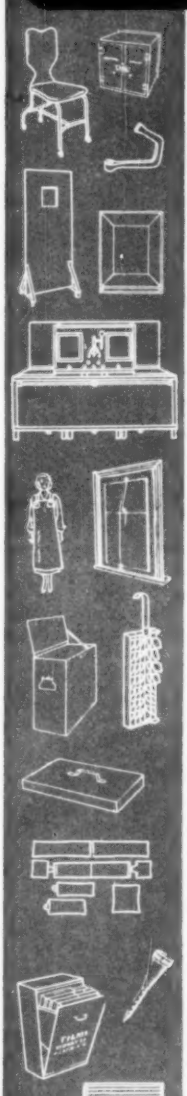

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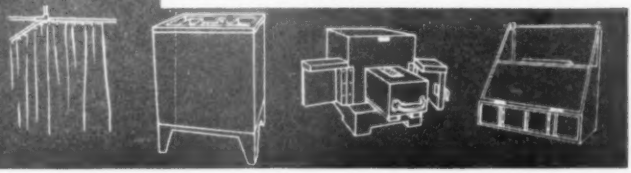
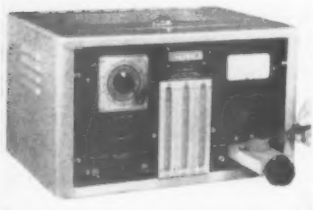


PRODUCTS AND MATERIALS

Pulse Generator

Spencer-Kennedy Laboratories, Inc., 186 Massachusetts Ave., Cambridge 39, Mass. The model 503 fast-rise pulse generator produces a rectangular pulse that has a rise time of less than 10^{-9} sec. The width of the pulse, controlled by an external cable, may be as short as 2×10^{-9} sec. Pulse amplitudes, of either polarity, are available in the range 0.1–100 volts. A single pulse, controlled by an external trigger, or internally controlled repetitive pulses, with repetition rates from 50 to 150 per sec, may be produced.

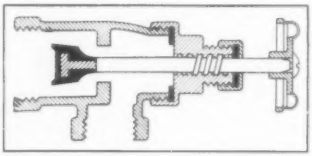


Proportional Counter

Nuclear Measurements Corp., 3339 Central Ave., Indianapolis 5, Ind. The model PC-3 α,β,γ-counter has scaling factors of 10, 100, and 1,000, and a maximum counting rate of 1,000,000 cpm. Counting geometry is 2π, but a special chamber for 4π counting is available. Alpha background is 5 cph, beta background is about 2 cpm per cm² of chamber. Results are displayed on a six-digit register. An automatic pre-set interval timer and an automatic gas-purge cycle are built in. The multiple purpose chamber accepts samples up to 2¼ in. in diameter; several exchangeable special-purpose chambers are also available. The regulated high-voltage supply is variable in the range 750–2,500 volts.

Mercury Trap

Chemiquip Co., 6 E. 97th St., New York 29, N. Y. This device is designed to trap mercury blown from manometers, and to achieve equilibrium readings in 10 sec. It also dampens surges and pulsations, filters actuating media, and prevents loss of mercury at normal operating pressures. Containers that hold 100 cm³ and 125 cm³ are available. For differential manometers, installation is made at both ends; for absolute manometers, installation is made at the open end.

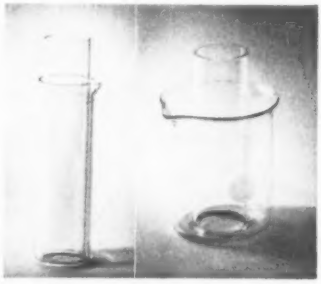


Valve Seal

Rodic Chemical and Rubber Corp., Allen Ave., New Brunswick, N. J. This cone-shaped seal closes in the same direction as the movement of the liquid. The seal is leak-proof, according to the manufacturer. The resilient member is not deformed by pressure, and is built to withstand oil, grease, steam, water, and most industrial chemicals.

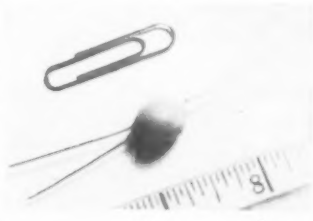
Respirator

Mine Safety Appliances Co., Braddock, Thomas and Meade Sts., Pittsburgh 8, Pa. This respirator has a filter efficiency of 99.99% against particles 0.3μ in size, according to the manufacturer. It has been designed to protect personnel against oxides of beryllium, radioactive dusts, and similar airborne particulate materials. The facepiece affords a quick, gas-tight fit regardless of facial shape or size.



Beakers

Atomlab, Inc., 489 Fifth Ave., New York 17, N. Y. The blood-plasma beaker (left) has a capacity of 10 ml, and is made of Pyrex. A G-M tube can be inserted in the center for counting small volumes of low-activity samples where self-absorption is an important factor. The Marinelli liquid-volume beaker (right) has a capacity of 100 ml. A G-M tube can be inserted in the center for radioassay work.



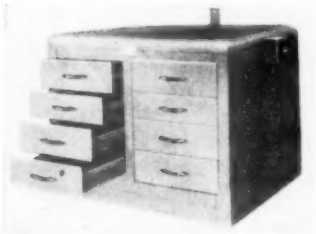
Pulse Transformers

PCA Electronics, Inc., 6368 DeLongpre Ave., Hollywood 28, Calif. These miniature pulse transformers have a pulse-width range of 0.2 μsec to over 5 μsec, when used as blocking oscillators. Standard frequency response is from 100 kc to 30 Mc, which can be shifted to higher or lower frequency

if required. Two, three, and four winding units, with and without center taps, are obtainable. The rise time is said to be fast, with a minimum of decay.

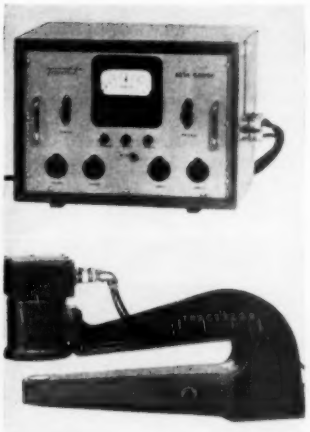
Mercury

Bethlehem Apparatus Co., Inc., Front and Depot Sts., Hellertown, Pa. Mercury for use in instruments that require a high degree of accuracy is available in a bottle with a flexible dispensing tip that delivers the mercury directly to the instruments; exposure to impurities in the air is thus eliminated.



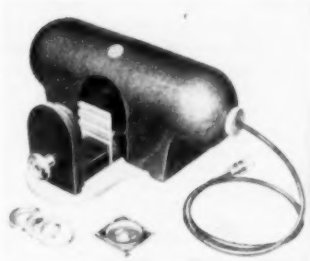
Portable Oven

Grieve-Hendry Co., Inc., 1101 N. Paulina St., Chicago 22, Ill. The model TD oven is thermostatically controlled; temperature is adjustable up to 325° F. The oven has 8 drawers, each $2 \times 11\frac{1}{2} \times 23$ in., that permit baking of different materials at the same time or materials inserted at intervals. Forced circulation is provided by an electric fan; an adjustable damper controls the volume of air circulation. Ovens can be provided with an outside reading thermometer; 60-min, 6-hr, or 12-hr timer; and an exhaust chamber adapter for venting off fumes. The unit operates on 110 volts.



Beta Gage

Tracerlab, Inc., 130 High St., Boston 10, Mass. The model BG-1 absorption beta gage can measure the thickness of materials weighing up to about 600 mg/cm². The gaging unit can scan a sheet up to 15 in. in width. Accuracy of the measurement is 2%, it is claimed. The source used is Sr^{90}; a solenoid-controlled safety shutter shields the source, and a warning light indicates when the shutter is open. The 20-μa, 6-in. meter can be calibrated to meet the needs of the installation. Standardization is carried out manually. A backscatter gage is also available. It can measure the thickness of materials weighing up to 250 mg/cm²; accuracy is said to be 2%.

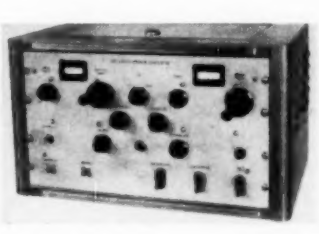


G-M Tube Shield

Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill. The model 3030A shield is arranged for mounting a glass-side-window G-M tube horizontally. The sample may be placed close to the tube, the entire assembly being shielded by 2½ in. of iron. The shield can hold sample holders that are 1, 1¼, 1½, or 1¾ in. in diameter. By varying the sample distance, geometries of 5, 5.9, 7.6, and 9.5% may be used. Aluminum-foil absorbers less than ⅛ in. in thickness can be inserted.

pH Meter

North American Philips Co., Inc., Research and Control Instruments Division, 750 S. Fulton Ave., Mount Vernon, N. Y. This instrument is designed for all *p*H work, for potentiometric titrations, and for oxidation-reduction-potential investigations. The range of measurement is 0–14.15 *p*H and 0–1,415 mv; accuracy is said to be 0.01 *p*H or 0.5 mv. The device is directly calibrated for use with glass, quinhydrone, and hydrogen electrodes; it can also be used with platina electrodes. Controls are provided which correct for temperature variations and for asymmetric potentials. The chemical cabinet contains four electrodes, a selection of glassware, a 0–50° C thermometer, quinhydrone, KCl, and tablets for buffer solutions.



Sweep Generator

Radio Corporation of America, RCA Victor Division, Harrison, N. J. The models WR-40A and WR-41A sweep generators have continuous tuning

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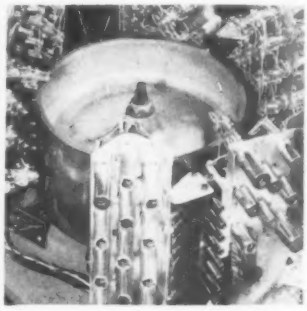
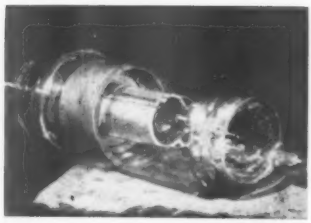


Computer

Computer Research Corp. 3348 W. El Segundo Blvd., Hawthorne, Calif. Shown above is the magnetic-drum memory of the model CRC 102 general purpose computer. This drum can store 1,023 words; word lengths of 42 binary or 14 octal digits can be handled. The computer can alter its own instructions in accordance with information it produces, and make many binary decisions in its operation. The instrument can also solve any type of arithmetic or mathematical problem in which characteristics can be expressed in numerical form, such as simultaneous algebraic equations, matrix algebra problems, ordinary and partial differential equations, and elliptic, hyperbolic or integral equations.

Timing Relay

Thomas A. Edison, Inc., Instrument Division, 29 Lakeside Ave., West Orange, N. J. The model 207 miniature thermal timing relay can be obtained with delay periods in the range 5–120 sec. and heater voltages of 6.3, 27.5, and 115 volts, a-c or d-c. It is compensated for ambients from −60° to +85° C. Contacts are rated at 2.5 amperes at 125 volts, a-c, or 1.0 amperes at 125 volts, d-c.



Thyratron

Sheldon Electric Co., 68–98 Coit St., Irvington 11, N. J. The MT-1530 mercury thyratron is designed to control high d-c voltages, and can be built as a negative or positive control tube. Its peak anode voltage is 15,000 volts, forward or reverse. The 5.0-volt, 30-ampere cathode is completely shielded. The average plate current is 15 amperes, with a peak of 100 amperes; the tube will take a 1,500-ampere surge that has a maximum duration of 0.1 sec. Tubes of this type, built to meet specific requirements, can also be obtained.

LITERATURE AVAILABLE

Surveying. Booklet describes geological surveying with portable G-M counters. *Nucleonic and Radiological Developments, Ltd., 77 King's Rd., London, S. W. 3, England.*

Repeater. Bulletin describes device for increasing accuracy of vacuum-tube voltmeter. *Keithley Instruments, 8868 Carnegie Ave., Cleveland 15, Ohio.*

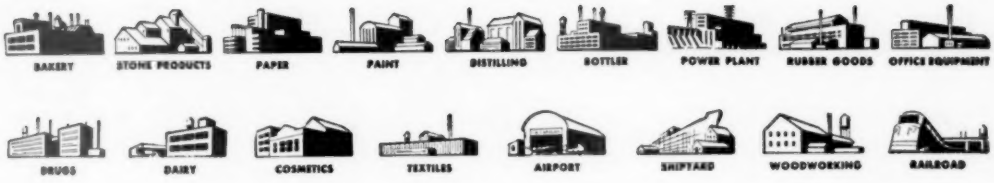
Micrometer positioners. Engineering data folder describes devices for use in relay-control circuits. *Automatic Temperature Control Co., Inc. 5200 Pulaski Ave., Philadelphia 44, Pa.*

Anti-rust paint. Bulletin describes rust-preventative paint. *The Monroe Co., Inc., 10703 Quebec Ave., Cleveland 6, Ohio.*

Publication. House publication describes technical products and their applications. *Polaroid Corp., Cambridge 39, Mass.*

Instruments. Folder contains sheets describing line of detection instruments. *Landswerk Electrometer Co., 140 W. Providencia Ave., Burbank, Calif.*

Decontaminating agent. Technical Bulletin No. 2 contains section on use of an organic complexing agent for radioactivity decontamination. *Bersworth Chemical Co., Framingham, Mass.*



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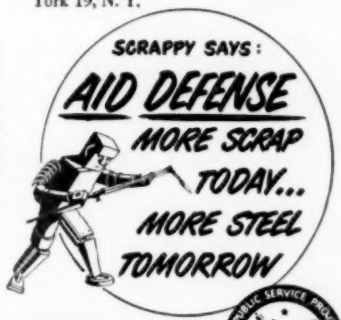

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LETTERS

Binary vs Decade Scalers*

To The Editor:

By nature, information is presented on a yes-no basis, i.e. on a scale of two. In the isotope laboratory we run head-on into this in the scale-of-64 counter (or scale of 2^n). If the book on the language of Utopia were written, you would find there, among other curious features, that the Utopians reckon, not as we do to the base 10, but to the base 2. The power of such a notation is small, but they escape this weakness by habitually handling large numbers in a logarithmic notation. This meets with enormous opposition among their bankers; in fact the bookkeepers, in contrast to the bookmakers, won't have anything to do with logs. Some of them condense their entries by a factor of 3 by using a private notation to the base 8. You see, bankers have to account for the last cent even in a sum of $100,000,000.00. But the schoolchildren think arithmetic not so bad and find the multiplication tables "duck soup." We, however, shall long be stuck with our decimal system, so must adapt our ways to fit it—unless we can adapt our machines instead, and so save our minds the trouble.

These animadversions were engendered by a sequence of events that must have happened in somewhat parallel fashion to every worker in an isotope laboratory. The scaling circuit burst upon me as overwhelmingly ingenious. The interpolation however was a real "pain in the neck." Moreover, it seemed as though I was never done with making blunders. Before my adaptation had become complete, decade scalers appeared in the advertisements. We bought one. How convenient! It began skipping numbers. How inconvenient! It was at the repair shop and I returned to the scale of 64. Having tasted cake, I was an absolute rebel about being put back on bread.

The fact is that decade scalers do depend on critical balance in their electronics, and are considerably more prone to get "out of whack" than the simple Higinbotham (or other) scale of 2^n. There might be fewer troubles if one just decided to stick to "old tried and true" and fit one's ways to one's instrument.

My acquaintance with isotope laboratories is not extensive, but I gather that the usual habit is to count samples for a fixed length of time. This time may be unitary (1 min) or a round multiple (10 min or 100 sec or 1,000 sec). It makes the mental arithmetic easy, to put total counts into counting rate. This is of course necessary in correcting for background activity or in comparing samples. If we wish to do it on the basis of raw counts, then we must count everything for the same length of time—which amounts to dealing with the counting rates. Even though "rate" is not written down, it is tacit in one's computations.

The first consideration is not ease, however, nor even the likelihood of blunder. Both of these are corrigible by a proper mobilization of the will. The precision of the technique should properly take precedence, and in measuring stochastic phenomena this means continual attention to statistical validity. One needs always to make sure that one has recorded enough events so that mere chance fluctuations will not vitiate one's conclusions. According to conventional statistical theory, the most useful measure of scattering about the observed central tendency of observations on a population is the standard deviation, or standard error, σ. For simple yes-no events, like counting rays, σ is equal to the square root of the number of events.

Note that it is the root of a number, not the root of an event. We must not attribute physical dimensions to a mere "yes," which is all we see in an event when all we do is count it.

So the standard error is equal to the root of the number of counts. The percentage error is $100(\sqrt{c}/c)$, which is the same as $100(1/\sqrt{c})$.

Therefore, choose to count to a total number, c, large enough so that the reciprocal of its root is satisfactorily small. Obviously if one halves the number of counts taken, the percentage error will be multiplied by $\sqrt{2}$.

One's prime interest, therefore, is in the total counts taken, and not in standardizing the counting time. One must be willing to take whatever time is needed to attain the desired precision.

The counts are as many as we wish to spend the time counting. As counts go up, σ goes up. The reason per cent error goes down is because the ratio of σ to counts is going down (counts go up as first power of time and σ only as the square root).

But what we wish to get at is really the activity of the sample. This is a rate, conveniently given in counts per second. The rate has its standard error, which is the standard error of the counts, divided by the time. We are forever having to correct sample counts for background. This has to be on the basis of counting rates. Errors are estimated as rates, and since the error of the difference of two values is equal to the root sum of squares of their errors, one must keep in mind that these errors must all be in the same units, therefore not percentage errors. One can bear a large percentage error in a background count, if the background rate is small compared to the sample rate. Browning† has analyzed the whole problem very carefully and gives graphs to facilitate the choosing of optimum counting times.

As Browning shows, time is most profitably used when distributed between sample and background in proportion to the square roots of their counting rates. This is the same as running to a number of counts proportional to the three-halves power.

This rule always results in the background being run for a shorter time than the sample. One can therefore run the sample to a conveniently large number of counts, say 1,000 for 3% standard error, or 10,000 for 1%. Then start running the background and shut it off at some convenient number of counts, 10^m, or $64n$, at about the time that was taken by the sample. This will use more time on the sample than the optimum, but will only prove tedious if the sample is of low activity, under which circumstance there is no escape from the tedium anyhow. This is a situation which warrants a thoughtful assignment of counting time.

Having discovered that sample is in fact not much above background, not more than four times background, you see that this is only a preliminary run. So start running sample again.

While it is running, calculate the

* This is an invited letter. The editors invite further comment from readers.

† W. E. Browning, Jr., Nucleonics 9, No. 3, 63 (1951)

standard error of the net sample activity

$$\sigma_{net} = \sqrt{\sigma^2_{gross} \times \sigma^2_{background}}$$

Compare this with net sample activity and see by what number you have to divide it to bring it within acceptable limits. Square this number and you have the number of times the preliminary counts have to be run again, both sample and background. It is true that this is not the optimum division between sample and background counting, but the occasions when time required is extremely long, namely when the preliminary run shows σ_{net} to be fairly large compared to net sample counts, are exactly the occasions when the sample and background counting rates are nearly alike. For such samples the ratio of counting rates as well as their square roots is not much different from unity.

It is a workable scheme to run routine sample and background measurements to a predetermined number of counts, instead of to a predetermined time. This scheme makes the binary scaler thoroughly practical.

R. R. Newell, M.D.
School of Medicine
Stanford University
San Francisco, California

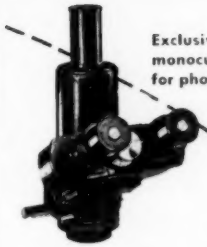
Kilocurie Cobalt Source

Dear Sir:

There has come to my attention an error in the value of a constant referred to in my article in the August, 1951, Nucleonics. The value for the cross section of cobalt-59 that I used in the text and in calculating the curves of activity vs days was 34 barns, and was obtained from the General Electric Research Laboratory "Chart of the Nuclides." A more recent book, i.e., "Nuclear Data" of the National Bureau of Standards, lists the cross section of cobalt-59 as 22 barns.

Although this correction makes a considerable difference in the calculated intensity of the source, it does not affect the purport of the article. If one applies the correction, the calculated curies of the cobalt source would be 1,045 rather than 1,643. However, for other reasons, the sources were designated nominally as 1,000 curies, so that the major premises of the article still remain in effect.

Bernard Manowitz
Reactor Science and Engineering Dept.
Brookhaven National Laboratory
Upton, New York



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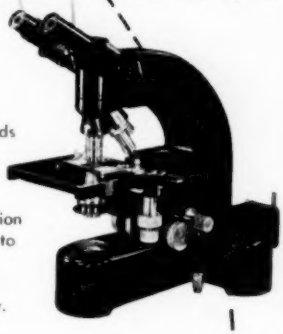

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INDEX TO ADVERTISERS

February, 1952

Advertising Council 81
Allied Radio Corp. 4
American Cancer Society . . 84
Bar-Ray Products, Inc. 77
Berkeley Scientific Corporation 65
Bersworth Chemical Co. . . . 84
Cambridge Thermionic Corp. 2
Cannon Electric Co. 70
Consolidated Engineering Corp. 5
El-Tronics Inc. 3
General Electric Co. 8
Kewaunee Mfg. Co. 67
Laboratory for Electronics, Inc. 7
Leitz, Inc., E. 83
Little, Inc., Arthur D. 75
McGraw-Hill Book Co. . . . 80
Minneapolis-Honeywell Regulator Co., Industrial Division 6
North American Aviation, Inc. 84
Nuclear Instrument & Chemical Corp. . . . . Fourth Cover
Nuclear Research Corporation 76
Penberthy Instrument Co. . . 84
Perkin-Elmer Corp. 69
Radiation Counter Laboratories, Inc. . . . . Third Cover
Servomechanisms, Inc. 71
Technical Service Corporation 76
Victoreen Instrument Co. Second Cover

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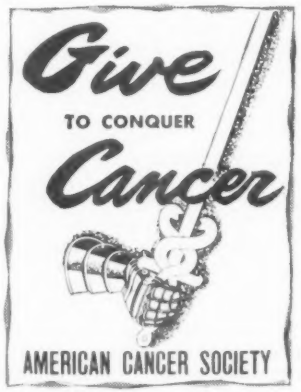

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1 2

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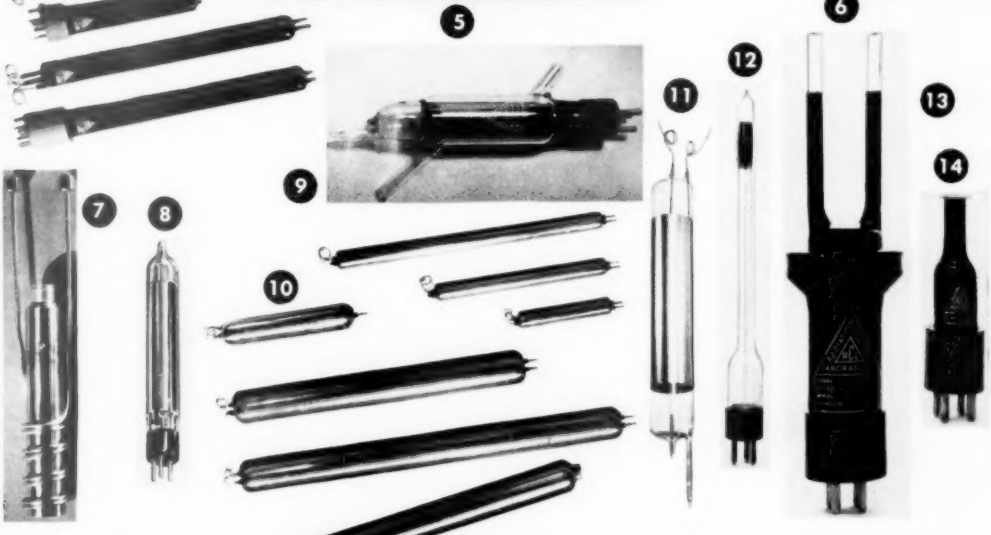
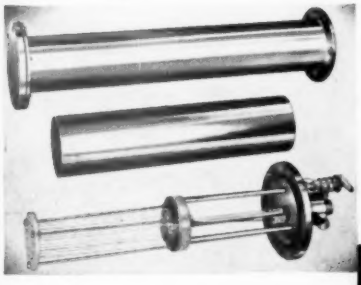
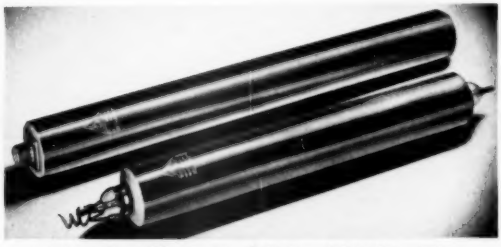


7 8 9 10 11 12 13 14

15



16



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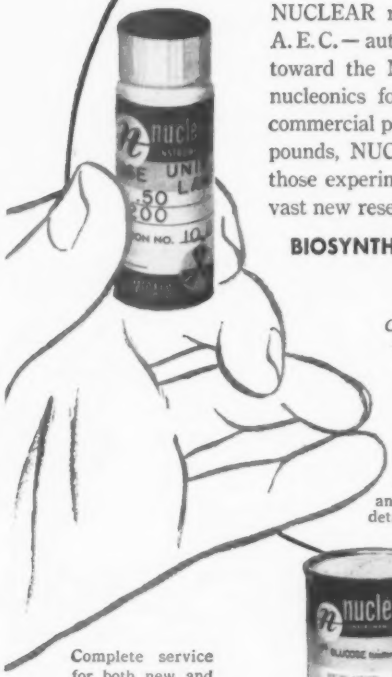

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